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Post Biological Solids Characterization and Removal from Pulp Mill Effluents

CH2M Hill, Inc, Corvallis, OR

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Post Biological Solids Characterization and Removal from Pulp Mill Effluents

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The study characterized the post biological solids in pulp and paper mill secondary effluent and evaluated various suspended solids removal techniques. Characterization was performed on samples from 9 mills, representing various locations, pulping processes and treatment system types. Results indicate the solids are mostly biological in nature. Coagulation by alum in conjunction with a cationic polymer appeared to provide the best results. Six solids removal techniques were tested but only mixed media filtration and sand filtration appeared effective enough to warrant further investigation.

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POST BIOLOGICAL SOLIDS CHARACTERIZATION AND REMOVAL FROM PULP MILL EFFLUENTS

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report summarizes the results of a study to characterize the post biological solids of several pulp and paper mill waste treatment operations. The nature of these solids did not suggest that these suspended solids would adversely affect the receiving streams. Several methods for removing these post biological solids were investigated and rated for effectiveness. If these solids eventually show detrimental effects on aquatic life this report will provide a useful guide for going about selecting the best technology to reduce their concentrations. The heavy metal content for 9 mills is also tabulated. For further information please contact Dr. H. Kirk Willard of the Food and Wood Products Branch, IERL, Cincinnati, Ohio.

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ABSTRACT

The objective of this study was to characterize the post biological solids in pulp and paper mill secondary effluent and to evaluate various suspended solids removal techniques. The study was initiated as a result of EPA guidelines development work, which might potentially require post biological solids removal to a level on the order of 10 mg/l. This bench scale work comprised Phase I of the project. A second phase of work has been proposed to extend these efforts to a pilot scale study (on site at several mills) of the most promising of the removal techniques as determined in the Phase I work. Phase II, however, has since been eliminated. Phase I was formulated in three parts; solids characterization; coagulation method optimization; and removal method evaluation.

Phase Ia, Solids Characterization, examined effluent samples from nine representative pulp and paper mills. The post biological solids resulting from secondary treatment of the mill wastewater were "fingerprinted" by 11 analyses for physical and chemical characteristics. An attempt was made to correlate these findings with geographic location, pulping process, and type of treatment process used at each mill. Results indicate that the suspended solids are mostly biological in nature. Biochemical and chemical oxygen demand (BOD and COD), volatile content, and nutrient content (Kjeldahl nitrogen and total phosphate) test results and microscopic examination tended to support this conclusion. The predominance of negatively charged particles indicated the potential effectiveness of trivalent aluminum and iron salts as coagulants.

Phase Ib, Coagulation Optimization, included evaluation of three inorganic chemicals (alum, ferric chloride, and lime) in combination with five polymers to determine the optimum coagulant and dosage. A jar-test apparatus was used on effluent samples from mills number 1, 2, and 3. Alum was selected for use with a cationic liquid polymer because this combination provided the best floc formation and the lowest supernatant total suspended solids (TSS) content after settling, for all samples. The cationic liquid polymer provided the most stable floc formation, and was the easiest to mix and feed.

Phase Ic, Solids Removal Techniques, included bench scale testing of six tertiary treatment processes for their effectiveness in solids removal, and response to the range of solids characteristics measured in Phase Ia. The methods tested included: Coagulation/Sedimentation; Mixed Media Filtration; Sand Filtration; Microstraining; Dissolved Air Flotation; and Magnetic Separation.

The results of the Phase Ic testing indicated that of the six methods tested only sand filtration and mixed media filtration appeared to produce

results which would warrant further testing. Variable TSS removals, ranging from 20 to 70 percent, were observed with the bench scale equipment used.

The purpose of this study was to identify those solids removal methods which exhibit enough potential for significant solids removal to justify pilot scale testing on site. However, a joint industry-regulatory task committee concluded from the Phase I data that none of the technologies investigated appeared to remove suspended solids better than simple setting. Thus, no further work on this project was merited.

This report was submitted in fulfillment of Contract No. 68-03-2424 by CH2M Hill, Inc., under the sponsorship of the U.S. Environmental Protection agency. This report covers the period June 1, 1976 to April 30, 1977, and work was completed as of June 15, 1977.

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ABBREVIATIONS AND SYMBOLS

AC	acre
ADT	air dryed ton
AL	aerated lagoon treatment
API	American Paper Institute
A/S	activated sludge treatment
BK	bleached kraft mill
BLMGO	MgO base bleached sulfite mill
BS	ammonia base bleached sulfite mill
C	chlorination process
CST	capillary suction time
D	chlorine dioxide process
DAF	dissolved air flotation
DIA	diameter
DMS	dimethyl sulfide
DT	detention time
E	caustic extraction process
gpm/ft^2	gallon per minute per square foot
GAL/T	gallon per ton
H	hypochlorite process
LB/D	pound per day
LB/T	pound per ton
MG	million gallons
MGD	million gallons per day
mg/l	milligrams per liter
ml/min	milliliters per minute
mm	millimeters
$m^3/s/m^2$	cubic meters per second per square meter
N	nitrogen
NC	north central United States
NCASI	National Council for Air and Stream Improvement
NH_3	ammonia
NO^x	oxides of nitrogen
NE	northeastern United States
NPDES	National Pollutant Discharge Elimination System
P	phosphorous
PS	pumping system
RAS	activated sludge recovery
S	southern United States
SOL	soluble
SWD	side-wall depth
T/D	tons per day
TKN	total Kjeldahl nitrogen
TOT	total
TS	total solids

ABBREVIATIONS AND SYMBOLS (Con't.)

TSS	total suspended solids
TVS	total volatile solids
VOL	volume
UBK	unbleached kraft mill
UF	ultrafiltration
VSS	volatile suspended solids
W	western United States

CONVERSION TABLE[a]

To convert from	to	Multiply by
gallon (U.S. liquid)	metre^3 (m^3)	3.79×10^{-3}
gallon per minute (gpm)	metre^3 per second (m^3/s)	6.31×10^{-5}
gallon per minute per square foot (gpm/ft^2)	metre^3 per second per metre^2 ($m^3/s/m^2$)	6.79×10^{-4}
pound (lb)	kilogram (kg)	4.54×10^{-1}
pound per ton (lb/t)	kilogram/kilokilogram (kg/kkg)	5.00×10^{-1}
pound per day (lb/d)	kilogram per day (kg/d)	4.54×10^{-1}
million gallons per day (MGD)	metre^3 per day (m^3/d)	$3.79 \times 10^{+3}$
pounds per inch^2 (psi)	pascal (Pa)	6.89×10^{3}
tons per day (t/d)	kilogram/day (kg/d)	9.07×10^{2}

[a]Standard for Metric Practice. ANSI/ASTM Designation: E 380-76$^{\epsilon}$, IEEE Std 268-1976, American Society for Testing and Materials, Philadelphia, Pennsylvania, February 1976. 37pp.

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Dr. H. K. Willard
Mr. Gene Zanella

Mr. John Ruppersberger, Project Officer, provided additional valuable assistance.

SECTION 1

INTRODUCTION

GENERAL DESCRIPTION OF THE PROJECT

The objective of this study was to characterize the post biological solids in secondary effluent from nine pulp and paper mills throughout the U.S. and to identify, through bench scale tests, the tertiary solids removal steps which produce removals great enough to justify pilot scale testing. The study was designed to provide a better understanding of the chemical and physical characteristics of solids in the mill effluent, and to identify patterns of variance in these characteristics as they occur within a variety of pulping processes, geographical locations, and types of biological secondary treatment. The knowledge gained in this study should provide a basis for designing a more detailed mill-specific pilot scale study of solids removal techniques.

The project was funded by the Environmental Protection Agency (EPA). A Technical Review Committee was formed to provide input to the project during organization and data analysis. The committee included representatives of the industry, EPA, Institute of Paper Chemistry and NCASI (National Council for Air and Stream Improvement).

In developing 1983 effluent guideline limitations for the pulp and paper industry, EPA considered several alternatives for additional end-of-pipe treatment to remove suspended solids from biologically treated effluent. The technology identified in the development documents was based primarily on municipal wastewater treatment experience, since few pulp and paper mills had applied post biological solids removal technology. As a result, the data base from which to forecast suspended solids removals achievable on pulp and paper effluents is severely lacking. Moreover, the liquid-phase chemical constituents in biologically treated pulp mill effluents have dispersant properties which make coagulation and particle separation difficult in comparison to municipal effluent.

These facts led EPA to undertake the characterization studies reported herein, in an attempt to generate a more complete data base on the post biological solids characteristics and susceptibility to removal.

The results of this study, coupled with the subsequent pilot testing, should provide a better understanding of the technology necessary to meet future effluent suspended solids guidelines.

PROJECT CONCEPTION

An important factor in the design of this study was the probable requirement for tertiary treatment to remove post biological suspended solids, as a result of application of effluent limitation guidelines.

This study was conducted in three steps to provide both a knowledge of the character of post biological suspended solids, and to determine the most promising methods for removing these solids.

The first step (Phase Ia) consisted of a systematic study of the quantity and character of suspended solids in the effluents from nine mills, to provide a current picture of the post biological solids which are present in secondary-treated effluent. A review of related literature provided background information on the quantity and character of typical pulp and paper mill secondary effluent, and on the most effective solids removal methods.

Mill samples were analyzed for types of suspended solids present and physical and chemical characteristics of those solids. An attempt was made to correlate these data with the type of pulping process as well as the treatment process employed at each mill.

The second step (Phase Ib) consisted of an evaluation of the various chemical coagulants and organic polymers available, to determine the most effective chemical and the optimum dosage. The chemicals tested were chosen on the basis of the characteristics of the solids determined in the first step. On this basis, the number of coagulants considered was reduced to three inorganic chemicals and five polymers.

The third step (Phase Ic) included bench scale testing of six specific alternative processes which might be used for post biological solids removal. The guidelines Development Document identified mixed media filtration as the most likely process, but also suggested microstraining, coagulation/sedimentation, flotation, and sand filtration. These five plus magnetic separation were tested on samples from four of the nine representative mills.

Analyses were performed in both EPA and CH2M Hill Laboratories in Corvallis, Oregon.

Three of the test mills were located close enough to allow analyses to be performed on "fresh" samples. However, to try to determine the effect of time degradation on samples from more distant mills, the local samples were split into two components. One component was immediately analyzed and the other refrigerated for approximately 5 days (the maximum transport and storage time from the other six mills). The same analyses were performed at the end of the storage period to try to develop factors related to storage effects.

SECTION 2

CONCLUSIONS

Characterization of the suspended solids in biologically treated effluent from nine pulp and paper mills covering a range of pulping processes, geographical locations, and biological treatment processes was completed, along with bench scale comparative evaluation of potential treatment processes for removal of the post biological solids for four mills.

Coagulation/sedimentation, mixed media filtration, sand filtration, microstraining, dissolved air flotation and magnetic separation were compared to determine the relative degree of suspended solids removal in each process, and to identify the most promising process(es) for subsequent on-site pilot testing in a later phase of the project.

Conclusions from the characterization and bench scale comparison tests are:

Characterization

Average suspended solids (TSS) levels for the mills studied were generally between 50 and 100 mg/l.

The physical and chemical characteristics of the post biological solids were variable, but overall averages showed 0.4 kg(lb)BOD/kg(lb)TSS, 1.8 kg (lb)COD/kg(lb)TSS, 0.83 kg(lb)VSS/kg(lb)TSS, 0.07 kg(lb)N/kg(lb)TSS, 0.01 kg (lb)P/kg(lb)TSS. The solids had a mean particle size by volume of 0.5 to 1.5 microns, and were negatively charged.

The concentration of TSS, based on a mill to mill comparison, showed no clear correlation to the type of pulping process, geographical location, or type of treatment process (i.e., aerated lagoon versus activated sludge process). In general, the range of TSS levels measured in three separate composite samples from the same mill was comparable to the difference in TSS levels observed from mill to mill. Examination of variations at individual mills, from mill NPDES permit reports, indicates wide variations in TSS levels at a given mill. At some mills, the long-term NPDES data indicates a seasonal increase in TSS levels during cold weather months.

The BOD and COD per unit of TSS indicates a largely carbonaceous makeup of the post biological solids. The BOD and COD per unit of TSS were generally higher for higher-rate treatment systems (i.e., short lagoon retention time or low activated sludge age), but otherwise did not differ according to mill pulping process or location.

The volatile solids content (VSS/TSS) of the post biological solids shows a possible relation to mill product in that high TSS ash content was observed at mills using inorganic fillers and additives. A secondary effect appears to be treatment system loading rate, with the high-rate systems showing a higher volatile (lower ash) TSS.

The nitrogen and phosphorus content of the post biological solids suggest that the solids are primarily biological in nature. Apparent solids crude protein content (Kjeldahl N x 6.25) ranged from 25 to 75 percent by weight, and averaged about 40 percent. Comparison of N and P content of the post biological solids with bacterial culture data suggests that on average, perhaps one-fourth of the solids are of non-biological origin. Individual mill data indicate that the non-biological fraction may range up to one-half of the TSS.

Negative particle charges were observed in all samples. There was no correlation between magnitude of particle charge and TSS concentration.

The mean particle size data show that a major proportion of the suspended solids are less than a few microns in diameter, and will likely require coagulation to be amenable to physical removal down to low TSS levels. Correlation between size distribution and TSS susceptibility to removal by treatment was poor.

Refrigerated storage for a period of up to 5 days shows no conclusive evidence of significant changes in the characteristic parameters measured in this study when compared to fresh 24-hour composite samples.

Storage during 24-hour composite sample collection showed no significant difference in TSS concentration as compared to fresh grab samples collected during the same period. However, solids characterization studies were performed on 24-hour composite samples only, so no data were obtained which would quantify the storage effects during the 24-hour composition period. Sample visual appearance and Imhoff cone observations suggest that some type of natural coagulation may occur during the compositing storage period. This emphasizes the need for pilot data intended for commercial scale-up to be collected on fresh effluent.

Metals analysis of the effluent samples before and after filtration, by argon plasma emission spectrometry, were not sufficiently sensitive to allow assay of the inorganic constituents in the post biological solids by difference. While the analytical sensitivity to determine weight-percent metals in the solids was not achieved, there was no evidence of gross enrichment of metals in the solids such as might occur by adsorption on floc particles.

Microscopic observation of the samples showed the presence of bacteria and particulate debris of unidentified origin. Fiber-type solids were found only on occasion and represented only a minor proportion of the total particles observed.

Coagulant Testing

Analysis of alum, ferric chloride and lime as coagulants revealed that alum provided the most consistent flocculation at minimum dosages. Lime at dosages short of those inducing complete precipitation (including color) was least effective. Ferric chloride was comparable to alum in some tests, but provided less consistent flocculation at a given dosage on samples from the same mill.

Of the five polymers tested, none appeared significantly superior to the others. Nalco 634 and Percol 722 produced slightly lower supernatant TSS in jar testing. Nalco 634 liquid polymer was selected for use in the bench tests because it was easiest to mix and meter.

Considerable variability in optimum coagulant dose was observed, both from mill-to-mill and on different samples from the same mill. This suggests that full-scale pulp mill effluent coagulation facilities would require frequent monitoring and dosage adjustment.

Three methods of selecting optimum coagulant dosages were studied: jar testing, Buchner funnel freeness testing, and capillary suction time (CST) monitoring. Visual observation of jar tests was most successful in these studies.

The Buchner funnel or CST methods might be perfected as a control technique with further development. The mixed results in these studies were obtained because of overall net decreases in freeness which resulted from coagulant addition.

Alum dosages for optimum floc formation ranged from 40 mg/l to 180 mg/l (as $Al_2(SO_4)_3$) for the four mills studied. A concurrent polymer addition of 2 mg/l was judged optimum on the basis that significant further floc improvement was not realized until very high (5 to 10 times greater) polymer dosages were used.

TSS levels typically increased by up to several hundred mg/l upon coagulant addition at levels sufficient to produce floc formation. The implication of this phenomenon on the disposal of post biological solids removed by techniques requiring coagulation is significant. The amount of solids (dry weight basis) for disposal will be much greater than the apparent (influent minus effluent) quantity.

Mixed Media Filtration

Evaluation of five media combinations on one mill effluent indicated that a mixture of 30 percent Ilmenite (0.2 mm grain size), 30 percent sand (0.9 mm grain size and 40 percent anthracite (1.5 mm grain size) gave best TSS removal. Further study would be needed to determine if the optimum media combination is variable by mill.

TSS removal at a filtration rate of $3.4 \times 10^{-3} m^3/s/m^2$ (5gpm/ft^2) ranged from 43 to 69 percent without chemical coagulation, and from zero to 85 percent

with coagulation. The use of coagulants in an attempt to improve micron-size particle removal was generally ineffective because of the large increases in TSS level upon coagulant addition.

Consistent TSS removals to levels below 30-50 mg/l were not achieved in these tests; on-site pilot testing would be needed to define actual achievable TSS levels.

Dissolved Air Flotation

Dissolved air flotation tests at air-solids ratios of 0.06, 0.03 and 0.01 showed poor TSS removals.

On three of the four mills tested, TSS removals were less than 10 percent in every case and averaged nearly zero. On the remaining mill, removals of the order of 20 percent were observed.

Microstraining

Batch microstraining tests using 1 micron to 74 micron fabric mesh showed TSS removals in the range of zero to 37 percent without chemical coagulant addition. More than 20 percent removal was observed at only one of the four mills tested; two of the mills showed zero removal.

TSS increases were observed whenever coagulants were used.

The small micron mesh (less than 10 microns) blinded almost immediately, and no data were collected for these fabrics due to the impracticality of the short run times.

Coagulation/Sedimentation

Settling column tests conducted on three of the mill effluents with and without chemical coagulant addition showed TSS removals of zero to 20 percent without chemical addition, and net TSS increases with chemical addition.

For the test runs with chemical coagulation, a definite floc formation and settling occurred. However, this appeared to result from the substantial increase in TSS upon coagulant addition. The final supernatant TSS from the coagulated samples never recovered to less than the starting TSS, in spite of the formation and settling of a floc.

Massive chemical doses sufficient to precipitate color might effect net TSS reductions by coagulation/sedimentation, but this level of coagulation was excluded from this study.

Sand Filtration

Batch tests with a single-media 0.4 mm sand at $3.4 \times 10^{-3} m^3/s/m^2$ ($5 gpm/ft^2$) showed TSS removals between 14 and 68 percent without chemical addition and zero to 71 percent with chemical coagulants.

The results of the sand filtration tests were generally similar to the

mixed media filter tests. (See previous discussion.)

Magnetic Separation

Magnetic separation tests using a Frantz Ferrofilter with both steel wool and steel disc media showed typical TSS removals of the order of 20 percent or less.

Sample conditioning treatments including polymer and magnetite, alone and in combination, failed to significantly improve TSS removal.

Overview of Bench Testing Results

Of the processes tested, filtration (sand or mixed media) showed the greatest potential for post biological solids removal.

Chemical coagulation with alum and polymer was generally ineffective in improving TSS removal. The TSS levels consistently increased upon coagulant addition in levels sufficient to form a visible floc, and the net effect on TSS removal was typically deterimental rather than beneficial. (Color-precipitating chemical dosages were excluded from this study by design.)

The effluents tested showed variable TSS removals, from a standpoint of both mill-to-mill comparisons, and repeat observations at a given mill. On-site pilot testing is needed to adequately define consistently achievable TSS removals.

TSS removals down to the 5-10 mg/l levels commonly observed in municipal wastewater treatment were not achieved (an exception is mill 2, where initial TSS levels were of the order of 10 mg/l).

No definite correlation of TSS susceptibility to removal was observed with respect to mill process, location, treatment process, or TSS chemical and physical characteristics.

The availability of a reliable analytical technique to determine particle size distribution by weight (rather than number of particles) is probably a prerequisite to establishing reasonable correlations.

Effluent monitoring data from some mills suggest that seasonal (temperature-related) changes in TSS levels may be significant.

SECTION 3

RECOMMENDATIONS

Pilot-scale studies to define performance levels for post biological solids removal should be directed toward filtration (sand or mixed media).

Pilot-scale studies should be run at individual mill sites using fresh effluents.

Pilot plants should be at least of the $10^{-4} m^3/s$ (several gpm) size to generate sufficient backwash for backwash solids testing. Testing should include investigation of backwash disposal, fines recycle, and headloss buildup rate. The pilot plant program should also include further evaluation of seasonal variations.

A good analytical technique to measure TSS size distribution by weight should be established, to allow better evaluation of observed solids removal performance.

Analysis of the metals content of post biological solids - particularly calcium and magnesium - should be made to help identify the presence of non-biological solids such as calcium-lignin precipitates.

Further research to identify coagulants which can effectively agglomerate fine particles without increasing net TSS levels (short of inducing massive color precipitation) is needed.

Variation in post biological solids levels at individual mills should be studied to fully identify the effects of such variation on achievable solids removal efficiency. In particular, the effect of seasonal variation should be included.

SECTION 4

PROJECT EXECUTION

PHASE Ia - SOLIDS CHARACTERIZATION

An informal literature review provided the necessary technical and pertinent industrial data to develop this study. This information guided the design of the study and analysis of results. The review was compiled from sources such as EPA, NCASI (National Council for Air and Stream Improvement), API (American Paper Institute), and other published sources, and is included in Appendix A.

The review was separated into three sections: 1) General Studies on Solids Characterization and Removal Processes, 2) Specific Solids Removal Processes, and 3) Municipal Treatment Systems Solids Removal.

Industry cooperation was a key to the success of this project. Participant mills provided data about mill processes and treatment designs, sampling systems and special problems unique to each mill.

Site visits to each of these mills provided data on the mill pulping process, bleaching sequence, treatment design and past operating experience. At the same time, provisions were made for three samples (24-hour composite) of mill effluent to be taken. All samples were refrigerated in transit except the three samples from mills close to Corvallis, Oregon. These three fresh samples, analyzed immediately, provided a baseline for time degradation factors.

To determine the full range of post biological solids present in these samples and their physical and chemical properties, a number of tests were run. Eight of the tests were performed by EPA's laboratory analytical support staff. These tests were for COD (chemical oxygen demand; total and filtered), total suspended solids, volatile suspended solids, total and dissolved volatile solids, phosphorus (total and filtered), Kjeldahl nitrogen (total and filtered), ammonia, particle size (Coulter counter) and metals (total and filtered).

The following tests were run in the CH2M Hill Laboratory:

1. Particle size, by the direct count method using a microscope with a calibrated eyepiece.

2. Particle charge, by measuring zeta potential.

3. BOD (biochemical oxygen demand, total and filtered), by the

standard methods procedure. For purposes of this study, the filtered BOD was considered to be that passing the glass fiber filter used in the TSS determination.

Results of these tests are included in Section 5, Results and Discussion.

PHASE Ib - COAGULATION EXPERIMENTATION

This phase included evaluation and optimization of chemical coagulants for use in the bench scale tests (Phase Ic).

The chemicals tested included ferric chloride, alum and lime in combination with five polymers, to evaluate their relative coagulation efficiency.

The five polymers used were: Nalco 634, Percol 722, Calgon WT-300, Hercules 859, and Dow C31.

Four of the nine mill effluent samples were tested in Phase Ib.

The analysis at this stage included:

1. Jar testing.

2. Sludge filterability (Buchner funnel method).

3. CST (Capillary Suction Time).

PHASE Ic - SOLIDS REMOVAL TECHNIQUES

This phase covered evaluation of six potential tertiary unit processes for solids removal. Bench scale testing was performed on effluent samples from the same four mills tested in Phase Ib.

The purpose of this phase was to evaluate the relative efficiency of each process for post biological solids removal. Analysis of these data provided a reasonable basis for determining which unit processes would merit further testing in the Phase II work.

The results were analyzed to determine: 1) a relative ranking of each of the tertiary solids removal steps based on solids removal efficiency and performance consistency, 2) the impact of the range of solids characteristics measured in Phase Ia on the performance and relative ranking of tertiary solids removal steps, and 3) a sound technical basis for subsequent larger scale pilot testing of the two or three most attractive solids removal unit processes.

The specific procedures used in the bench scale analysis of each of 6 unit processes follows:

1. Mixed Media Filtration. Testing was conducted in 1-inch diameter laboratory filters operated in batch runs. The actual testing was divided into two steps. The first step consisted of media evaluation, in which preliminary test runs of three different media combinations on one mill effluent were made. The results of this initial testing were used to select the best media combination.

   Next, the performance tests were run using the selected media combination on the four mill effluents. TSS analyses were run on effluents with and without the chemical conditioners selected in Phase Ib.

   These tests provided a measure of the solids removal performance capabilities of mixed media filtration.

   One effluent sample was also shipped to a filter vendor for independent batch tests, to capitalize on vendor experience in this area.

2. Flotation. Dissolved air flotation tests for post-biological solids removal were made using a 2-liter, batch pressure chamber. Tests were conducted for three air/solids ratios on the four effluent samples, with and without the chemical conditioners selected in Phase Ib.

   Suspended solids removal efficiency was measured, together with float volume and float concentration.

3. Microstraining. Batch tests were run using four separate fabrics covering a range of micron sizes. These tests were conducted on each of the four mill effluent samples selected, and were run with and without chemical conditioners.

   The results of these tests gave a qualitative assessment of the impact of fabric opening size on suspended solids capture, the impact of chemical coagulation on relative rates for strainer performance and a qualitative assessment of probable strainer flow rates.

4. Coagulation/Sedimentation. Batch tests run in a 6-inch diameter plexiglass settling column determined the suspended solids removal achieved by chemical coagulation and gravity clarification. The coagulant dosage was based on the results of Phase Ib. Suspended solids removal versus depth was measured to determine removal efficiency.

5. Sand Filtration. This test run simulated a single-media filter. TSS removal and blinding rate were

measured. A preliminary test run was made on a single effluent source, using two sand grain sizes, to evaluate media effects. After a grain size selection was made, each of the mill effluents was tested.

Three test runs were conducted to simulate mechanical cleaning of the sand surface; two were run on a freshly drained sample, and one on a sample allowed to air dry for 24 hours prior to scraping the surface layer.

The thrust of the sand filtration experiment was to pursue a low-cost technology which might apply where natural site conditions allow the use of large percolation beds for solids removal.

6. Magnetic Separation. Magnetic separation is a relatively new process which has had very little commercial application for this purpose. A laboratory magnetic separation test unit (a Grantz Ferrofilter), loaned by the U.S. Bureau of Mines, Albany, Oregon, was used for this testing.

   The goal of the magnetic separation test was to obtain sufficient data for a cursory evaluation of magnetic separation for suspended solids removal efficiency.

MILLS SELECTED FOR USE

Nine producing pulp and paper mills participated in this study. Each mill provided data in their operations, included herein as Mill Data Summaries (Figures 1-9). The mills also allowed on-site visits and provided samples of their effluent.

The mills were selected on the basis of location, pulping process type, effluent treatment type, size and production, and willingness to participate. The Mill Data Summaries which follow give information about the mill and graphic representations of the treatment system used.

Of the nine mills, six were located in the west (mills 1 through 6), one in the southern region (mill 7), one in the north central region (mill 8), and one in the northeastern region (mill 9). Three of the western mills (mill 1, 2, and 3) were within one hour's drive of the EPA and CH2M Hill laboratories.

The mill processes included bleached and unbleached Kraft and bleached sulfite with both magnesium and ammonia base. Their production ranged from 3.11×10^5 kg/d (343 tons per day (t/d)) to 1.45×10^6 kg/d (1,600 t/d) of paper, kraft or sulfite products, or intermediary products such as bleached or specialty pulps. All mills except 2 and 9 recovered some by-products from their in-plant processes. All of the Kraft mills except mills 2 and 4 recovered methanol and mill 8 operates a methanol stripper with off-gas combustion in the lime kiln; mill 5 recovered crude tall oil; and mills 6, 7, and 8 reused condensate.

The mills treat their effluent with either aerated stabilization or activated sludge treatment systems. Most of the treatment systems include primary clarification and aerated ponds (mills 2, 3, 5, 7, and 8). Mill 2 also in-

Figure 1
MILL DATA SUMMARY

MILL NO. 1 **LOCATION:** West

TYPE: Unbleached Kraft & NSSC

PRODUCTION: Kraft Coarse & Corrugating Paper - 670 T/D
NSSC Corrugating Medium – 230 T/D

PULPWOOD: 86% Softwood Chips
14% Waste Paper

BLEACH PLANT: N/A

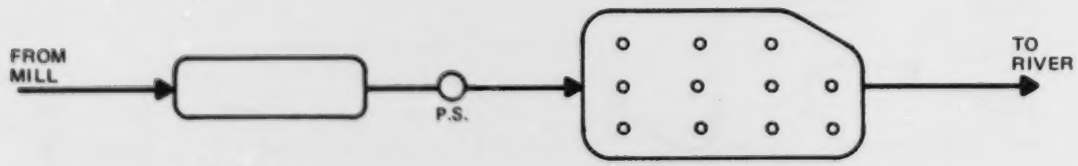
PAPER MACHINES: 3 Fourdrinier (164", 169", 184")

ADDITIVES: Wet end – Sizing: Alum Rosin; H_2SO_4; Guargum; UF Resin
Dry end – Wheat or Corn Starch
no Fillers; no Defoamer

RECOVERY SYSTEM: NSSC – 3 Stage Washing
Kraft – 4 Stage Washing
600 T/D Recovery Boiler

COMMENTS:
Turpentine Recovery – 1 Gal/T
30-40,000 LB/D Na_2SO_4 Lost to Sewer

EFFLUENT TREATMENT SYSTEM



PRIMARY SETTLING POND
VOL = 7 MG
D.T. = 3.5 HR @ 10 MGD & POND 80% FULL OF SOLIDS

AERATED POND
VOL = 90 MG
D.T. = 9 DAYS @ 10 MGD
TOT. AERATION = 550 HP

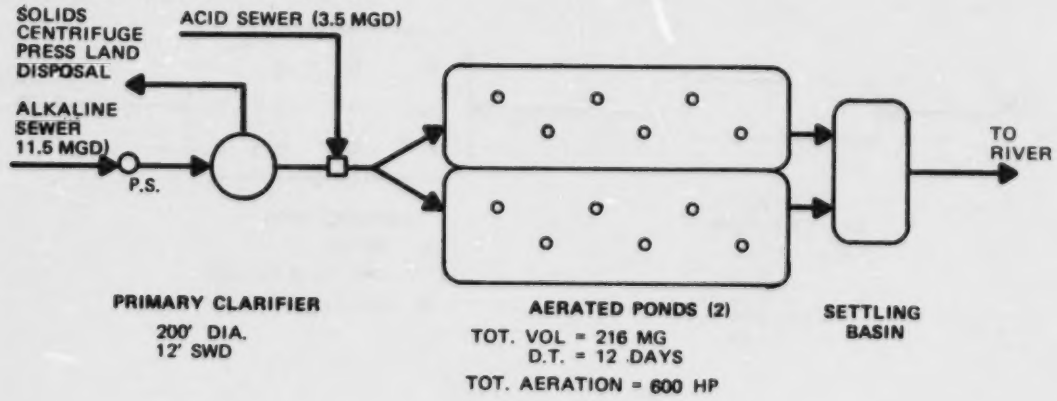
SELECTED EFFLUENT DATA

TYPICAL PRIMARY TREATED EFFLUENT:	FLOW	=	10.2 MGD (8.8 MGD – AVG TO RIVER) (11,300 GAL/T)
	BOD	=	257 MG/L (21,800 LB/D) (24 LB/T)
	TSS	=	105 MG/L (7,732 LB/D) (9 LB/T)
TYPICAL SECONDARY TREATED EFFLUENT:	BOD	=	31 MG/L (2,286 LB/D) (2.5 LB/T)
	TSS	=	62 MG/L (4,556 LB/D) (5 LB/T)

Figure 2
MILL DATA SUMMARY

MILL NO. 2	**LOCATION:** West
TYPE:	Bleached Kraft/Tissue
PRODUCTION:	Tissue – 250 T/D Bleached Pulp – 93 T/D Air dry
PULPWOOD:	65% Chips (Softwood) 35% Sawdust (Softwood)
BLEACH PLANT:	CEHH – With $Ca(OCl)_2$ Oxidation of E Stage Effluent for Color Reduction or CHEH
PAPER MACHINES:	2 – 194" Yankee Machines
ADDITIVES:	Wet End – Dyes, $CaCl_2$, Slimicide Dry End – Yankee Release Agent
RECOVERY SYSTEM:	4 Stage Washing 1 B&W 400 T/D Recovery Boiler
COMMENTS:	No By-Product Recovery

EFFLUENT TREATMENT SYSTEM



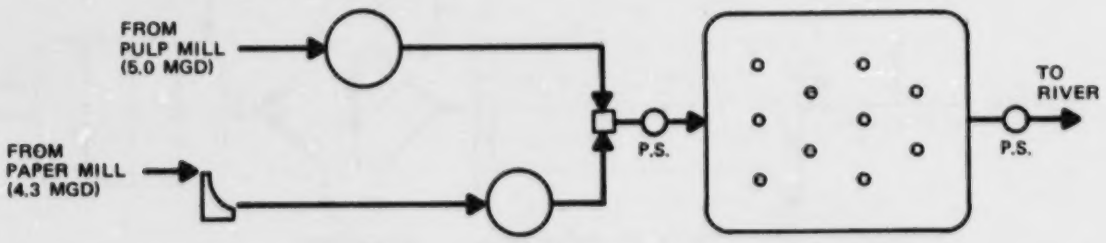
SELECTED EFFLUENT DATA

TYPICAL PRIMARY TREATED EFFLUENT:	FLOW	= 14.9 MGD (43,000 GAL/T)
	BOD	= NO DATA
	TSS	= NO DATA
TYPICAL SECONDARY TREATED EFFLUENT:	BOD	= 1,550 LB/D; 12.5 MG/L (4.5 LB/T)
	TSS	= 2,465 LB/D; 20 MG/L (7 LB/T)

Figure 3
MILL DATA SUMMARY

MILL NO. 3	**LOCATION:** West
TYPE:	Unbleached Kraft
PRODUCTION:	Kraft Paperboard – 1260 T/D
PULPWOOD:	100% Softwood Chips
BLEACH PLANT:	N/A
PAPER MACHINES:	2 Fourdrinier Machines (148" & 256")
ADDITIVES:	Wet End – H_2SO_4, Alum, Cationic Starches, Polymers Dry End – Potato or Corn Starch Fillers – 5-6 LB/T Simplot Clay, <1 LB/T Defoamer, Sizing Agent
RECOVERY SYSTEM:	Washing – Cont., 3 Stage; Batch – 4 Stage 2 CE 2400 T/D Recovery Boilers
COMMENTS:	Recover Turpentine & Methanol

EFFLUENT TREATMENT SYSTEM



SCREEN	PRIMARY CLARIFIER	FLOTATION THICKENER	AERATION POND
	130' DIA.	45' DIA.	VOL = 69 MG D.T. = 5.5 DAYS @ 10 MGD & 14 MG SLUDGE ACCUMMULATION TOT. AERATION = 750 HP

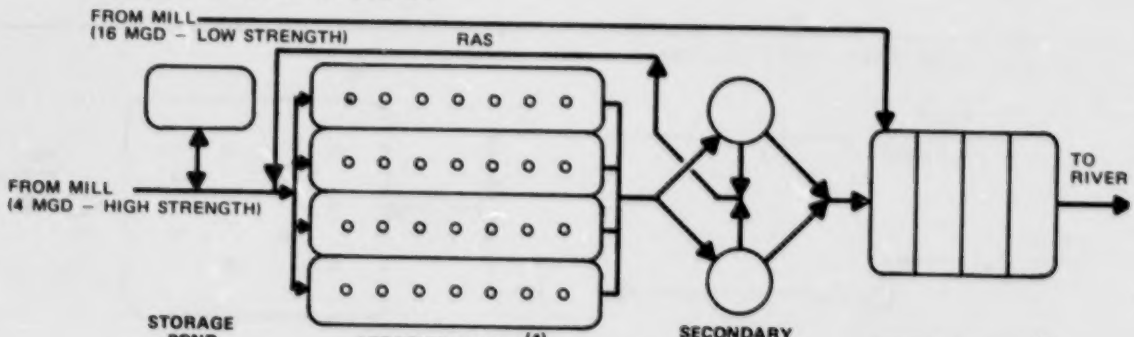
SELECTED EFFLUENT DATA

TYPICAL PRIMARY TREATED EFFLUENT:	FLOW	=	10 MGD; 8,000 GAL/T
	BOD	=	25,000 LB/D; 300 MG/L; 20 LB/T
	TSS	=	12,000 LB/D; 144 MG/L; 10 LB/T
TYPICAL SECONDARY TREATED EFFLUENT:	BOD	=	3,200 LB/D; 38 MG/L
	TSS	=	8,300 LB/D; 100 MG/L

Figure 4
MILL DATA SUMMARY

MILL NO. 4	**LOCATION:** West
TYPE:	MgO Base Bleached Sulfite
PRODUCTION:	Dissolving Pulp – 225 T/D Specialty Pulps – 225 T/D
PULPWOOD:	75% Roundwood 25% Chips (Mostly Softwood)
BLEACH PLANT:	CEH
PAPER MACHINES:	None
ADDITIVES:	None
RECOVERY SYSTEM:	4 Stage Washing 3 Recovery Boilers
COMMENTS:	Treat Evaporator Condensate & Venturi Scrubber Water

EFFLUENT TREATMENT SYSTEM



SELECTED EFFLUENT DATA

TYPICAL PRIMARY TREATED EFFLUENT: (EXCLUDING LOW STRENGTH FLOW)	FLOW	= 4 MGD; 9,000 GAL/T
	BOD	= 110,000 LB/D; 3,300 MG/L; 240 LB/T
	TSS	= 5,000 LB/D; 150 MG/L; 11 LB/T
TYPICAL SECONDARY TREATED EFFLUENT: (BEFORE SETTLING PONDS)	BOD	= 6,000 LB/D; 180 MG/L
	TSS	= 26,000 LB/D; 780 MG/L

Figure 5

MILL DATA SUMMARY

MILL NO. 5 **LOCATION:** West

TYPE: Bleached Kraft

PRODUCTION:
Paperboard – 880
Tissue – 50
Market Pulp – 200

PULPWOOD: 100% Softwood Chips & Sawdust

BLEACH PLANT:
Chips – CEHHD
Sawdust – CEHD

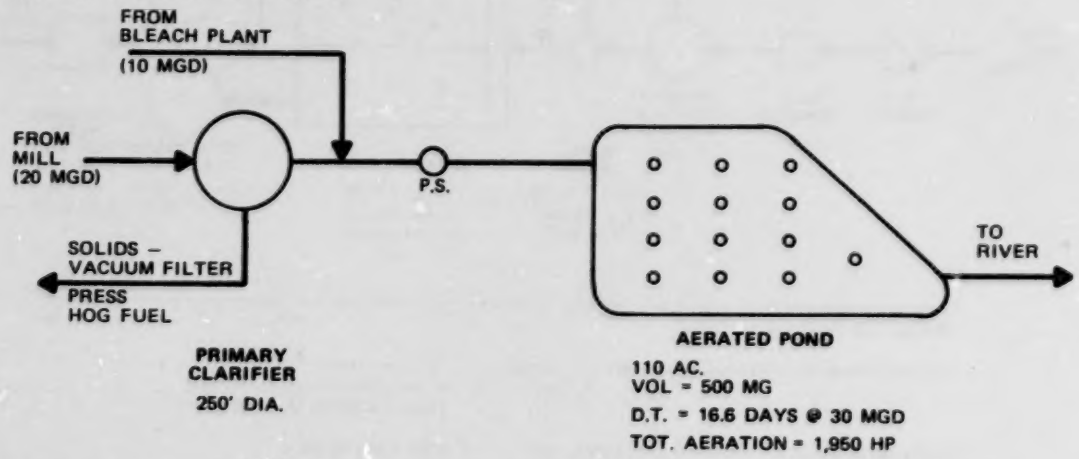
PAPER MACHINES: 3 Fourdrinier Machines (216", 216", 173")
1 IMPCO Wet Machine

ADDITIVES: Wet Strength; Sizing Agents; Dyes; Coating – Clay, TiO_2; Slimicides; Corrosion Inhibitor

RECOVERY SYSTEM: Recovery Boilers: CE 150 T/D; CE 300 T/D; B&W 300 T/D; B&W 400 T/D; 4 Stage Washing

COMMENTS:
Recover Tupertine & Crude Talc Oil
Soda Losses: 71 LB/T

EFFLUENT TREATMENT SYSTEM



SELECTED EFFLUENT DATA

TYPICAL PRIMARY TREATED EFFLUENT:
FLOW = 29.7 MGD (25,300 GAL/T)
BOD = 364 MG/L (90,200 LB/D) (80 LB/T)
TSS = 147 MG/L (36,400 LB/D) (32 LB/T)

TYPICAL SECONDARY TREATED EFFLUENT:
BOD = 33 MG/L (8,175 LB/D) (7 LB/T)
TSS = 79 MG/L (19,600 LB/D) (17 LB/T)

Figure 6
MILL DATA SUMMARY

MILL NO. 6 **LOCATION:** West

TYPE: Bleached & Unbleached Kraft; NSSC

PRODUCTION:
Kraft Linerboard – 450 T/D
NSSC Corrugating Medium – 250 T/D
Bleached Kraft – 200 T/D

PULPWOOD:
70% Softwood Chips
25% Waste Wood
5% Roundwood (Eucalyptus)

BLEACH PLANT: CEHPH

PAPER MACHINES: 3 Fourdrinier (144", 155", 120")

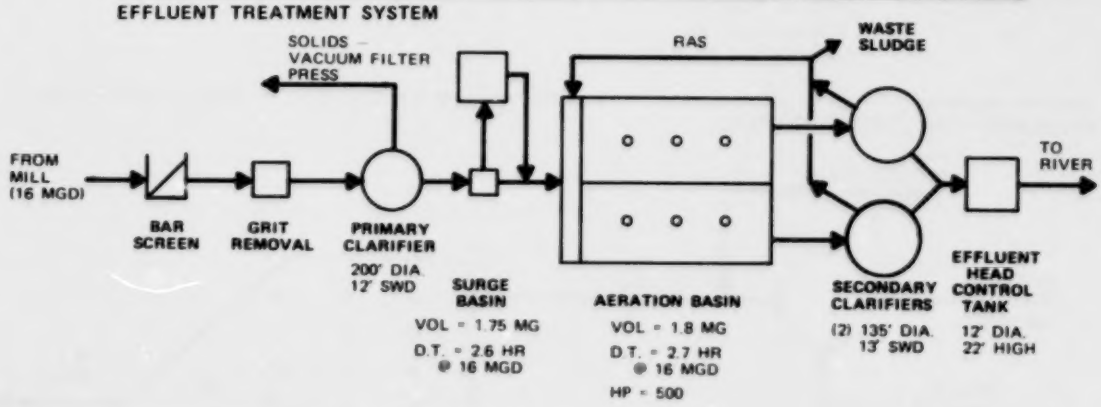
ADDITIVES:

Alum	Clay Coating	Onalon (Cr)
Rosins	Biocides	Waxes
Polymers	Defoamer	
Dyes		

RECOVERY SYSTEM:

COMMENTS:
Turpentine Recovery - 30 GPD
Soap Recovered – Burned

EFFLUENT TREATMENT SYSTEM



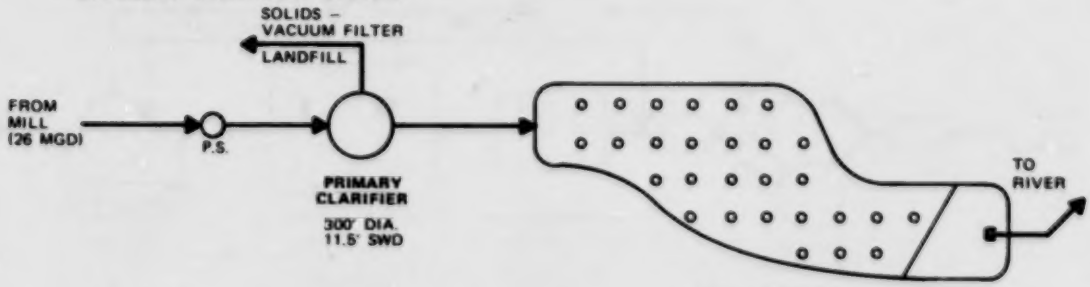
SELECTED EFFLUENT DATA

TYPICAL PRIMARY TREATED EFFLUENT:	FLOW	=	13 MGD; 14,500 GAL/T
	BOD	=	27,000 LB/D; 250 MG/L; 30 LB/T
	TSS	=	11,000 LB/D; 101 MG/L; 12 LB/T
TYPICAL SECONDARY TREATED EFFLUENT:	BOD	=	4,300 LB/D; 40 MG/L
	TSS	=	7,600 LB/D; 70 MG/L

Figure 7
MILL DATA SUMMARY

MILL NO. 7	**LOCATION:** South
TYPE:	Unbleached Kraft
PRODUCTION:	Paperboard – 1200 T/D Kraft Wrap & Bag – 400 T/D (150 T/D Bleached Kraft)
PULPWOOD:	40% Chips (All Softwood) 60% Roundwood
PAPER MACHINES:	5 Fourdrinier Machines (134", 136", 167", 157", 216")
ADDITIVES:	Alum Rosin Sizing Agent Wax Defoamer
RECOVERY SYSTEM:	2 Recovery Boilers 3 & 4 Stage Washing
COMMENTS:	Recover Turpentine, Soap, DMS Soda Loss – 180,000 LB/D

EFFLUENT TREATMENT SYSTEM



AERATED POND
VOL = 247 MG
63 AC x 12' DEEP
TOT. AERATION = 2025 HP
(27–75 HP UNITS)
D.T. = 9.5 DAYS @ 26 MGD

SELECTED EFFLUENT DATA

TYPICAL PRIMARY TREATED EFFLUENT:	FLOW	=	27 MGD (16,900 GAL/T)
	BOD	=	76,000 LB/D; 337 MG/L; 47 LB/T
	TSS	=	NO DATA
TYPICAL SECONDARY TREATED EFFLUENT:	BOD	=	13,000 LB/D; 58 MG/L (8 LB/T)
	TSS	=	14,000 LB/D; 62 MG/L (9 LB/T)

Figure 8
MILL DATA SUMMARY

MILL NO. 8 **LOCATION:** North Central

TYPE: Bleached Kraft

PRODUCTION: Coated Paper – 600 T/D
Bleached Hardwood Market Kraft – 325 T/D

PULPWOOD: 83% Roundwood (~50% Hardwood)
17% Chips

BLEACH PLANT: Kraft – CEDED
Groundwood – Peroxide

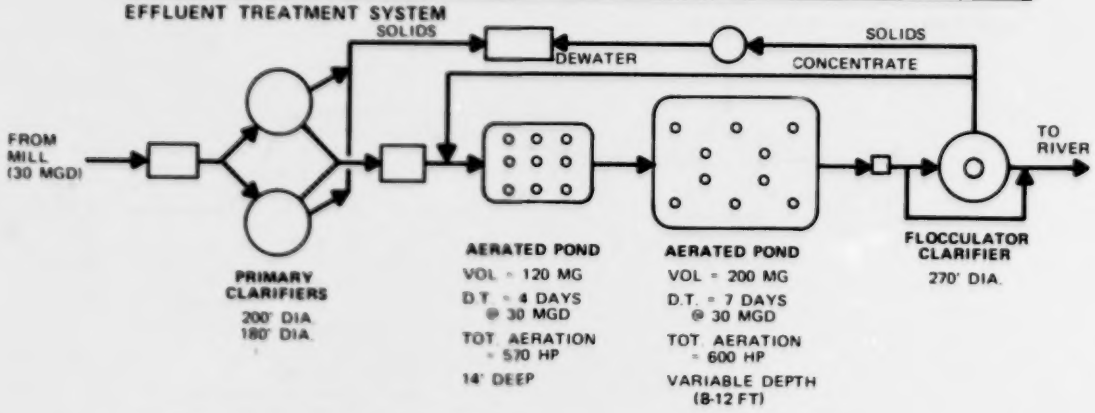
PAPER MACHINES: 2 Machines (300", 167")

ADDITIVES: Filler Clay, Rosin Size, TiO_2, Defoamer, Aluminum Hydrate

RECOVERY SYSTEM: 1 B&W Recovery Boiler – 800 T/D
3 Stage Washing
Steam Stripper

COMMENTS: Recover Turpentine & Soap
Soda Loss ~ 20 LB/T

EFFLUENT TREATMENT SYSTEM



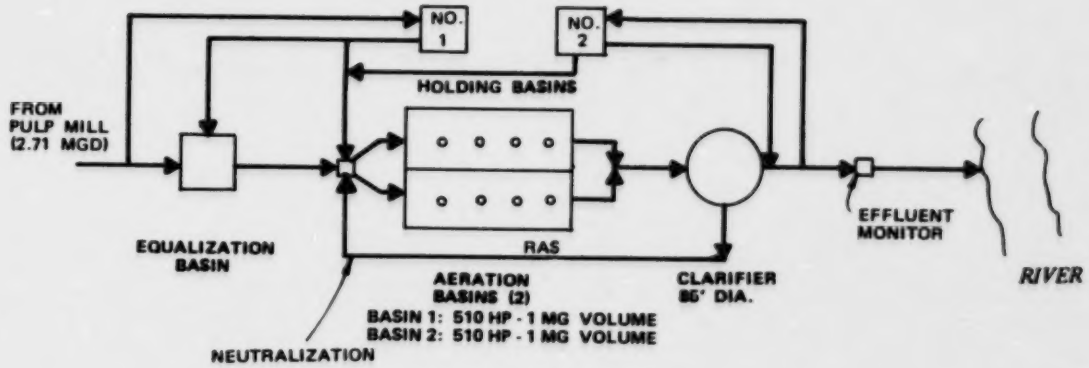
SELECTED EFFLUENT DATA

TYPICAL PRIMARY TREATED EFFLUENT:	FLOW	=	30 MGD (32,400 GAL/T)
	BOD	=	200 MG/L (50,000 LB/D) (54 LB/T)
	TSS	=	225 MG/L (56,300 LB/D) (61 LB/T)
TYPICAL SECONDARY TREATED EFFLUENT:	BOD	=	29 MG/L (7,260 LB/D) (8 LB/T)
	TSS	=	57 MG/L (14,300 LB/D) (15 LB/T)

Figure 9
MILL DATA SUMMARY

MILL NO. 9	**LOCATION:** Northeast
TYPE:	Ammonia Base Bleached Sulfite
PRODUCTION:	300 T/D Pulp Capacity
PULPWOOD:	85% Roundwood (All Hardwood) 15% Chips
BLEACH PLANT:	Single Stage Hypochlorite with Post Wash
RECOVERY SYSTEM:	2 Stage Washing Liquor Evaporation and burn in steam boiler
COMMENTS:	Papermaking effluent treated separately by physical-chemical treatment

EFFLUENT TREATMENT SYSTEM



SELECTED EFFLUENT DATA

TYPICAL PRIMARY TREATED EFFLUENT:	FLOW	=	2.71 MGD (4,500 GAL/T)
	BOD	=	2,875 MG/L (65,000 LB/D) (216 LB/T)
	TSS	=	239 MG/L (5,400 LB/D) (18 LB/T)
TYPICAL SECONDARY TREATED EFFLUENT:	BOD	=	90 MG/L (2,030 LB/D) (6.8 LB/T)
	TSS	=	137 MG/L (3,100 LB/D) (10 LB/T)

cludes a primary settling basin and mill 3 a flotation thickener for primary treatment. Mill 1 uses a primary settling basin, rather than a clarifier. Mills 4, 6, and 9 use activated sludge treatment systems.

Flow rates range from 1.14×10^4 m^3/d (3MGD) at mill 9 to 1.14×10^5 m^3/d (30 MGD) at mill 5.

SECTION 5

RESULTS AND DISCUSSION

PHASE Ia - SOLIDS CHARACTERIZATION

GENERAL

The analyses listed in Section 4 were run on the three samples from each mill to determine the physical and chemical characteristics of the post biological solids. The raw data from these analyses are included in Appendix C (Tables C-1 through C-4). Average values of several parameters for each sample have been plotted to provide a comparison of these parameters between the various mills.

Table 1 lists the observed physical and chemical characteristics of the post biological solids.

TABLE 1

SUMMARY OF
POST BIOLOGICAL SOLIDS CHARACTERISTICS

	Average of all Mills	Range of Averages for Individual Mills
BOD per unit of TSS (mg/mg)	0.40	0.16-0.60
COD per unit of TSS (mg/mg)	1.8	1.2 -2.8
Volatile Suspended Solids (% of TSS)	83	59 - 96
Nitrogen content (% of TSS)	7.0	4.0 -12.4
Phosphorus content (% of TSS)	1.03	0.46-2.35
Zeta potential of TSS (millivolts)	-20	-5 - -40
Mean particle size by volume (microns)	-	0.5 - 1.5

TOTAL SUSPENDED SOLIDS (TSS) CONCENTRATION

Figure 10 shows a comparison of TSS concentration of the samples analyzed. The range of concentrations observed was substantial, from under 10 mg/l to over 2500 mg/l. The greatest variation was at mill number 4, where excess activated sludge is wasted to the secondary clarifier effluent and is subsequently resettled in holding ponds downstream of our sample point. The most extreme excursions observed at mill 4 occurred during

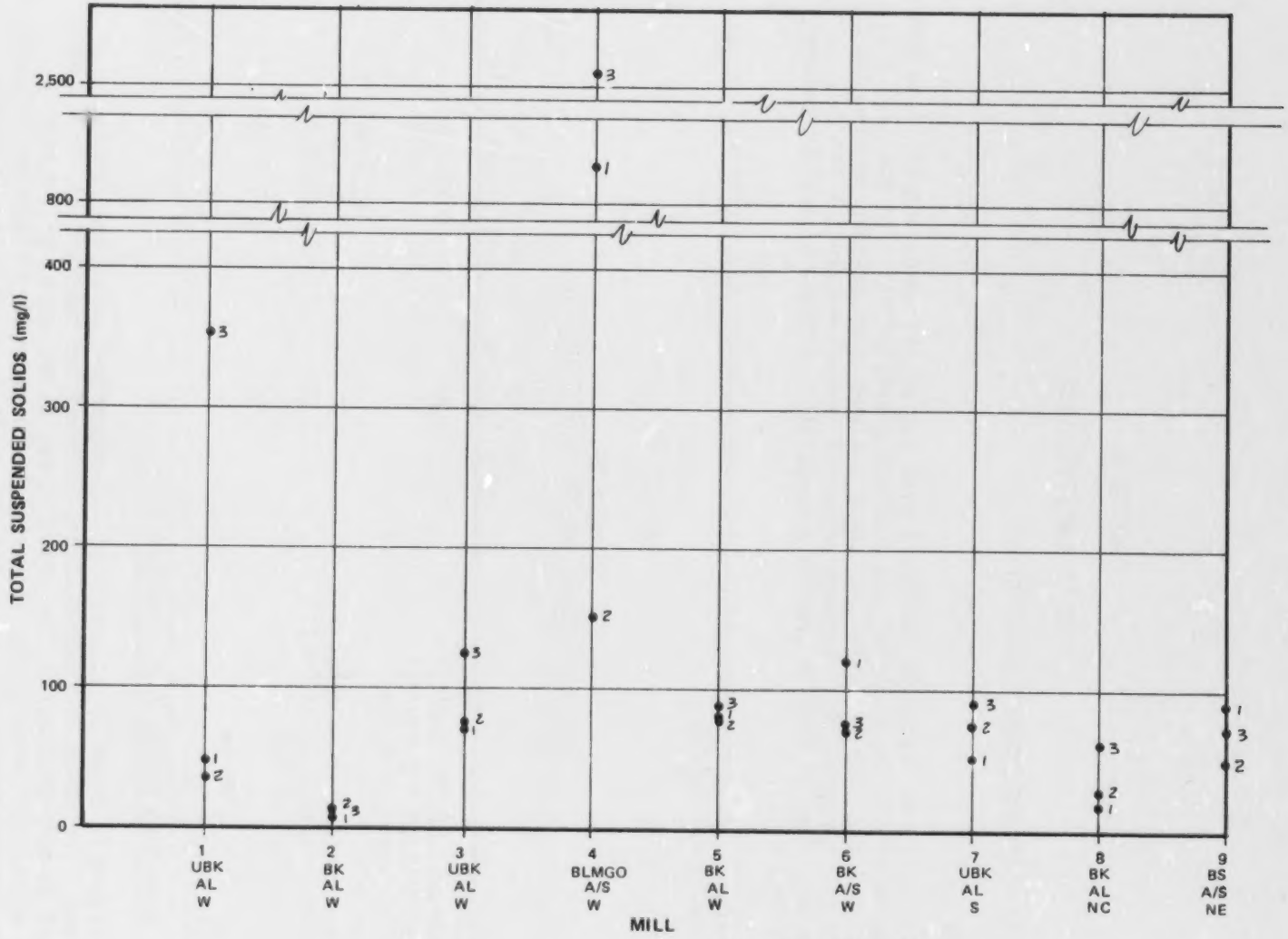


Figure 10
TOTAL SUSPENDED SOLIDS CONCENTRATIONS

treatment process operating problems. Mill number 1 experienced a significant increase of effluent TSS because of a seasonal change in quantity of effluent treated. The majority of the mills, however, averaged less than 100 mg/l TSS.

These data exhibit no significant differences attributable solely to mill location. The widest fluctuations both occurred in samples from mills located in the west, but otherwise the variation in TSS levels at a given mill were typically greater than the variation from mill-to-mill.

Activated sludge treatment systems are sometimes considered to produce better quality effluent. However, this figure shows that, in general, the aerated lagoon systems produce equal or better effluents (in terms of TSS concentration). This observation must be tempered by the higher feed BOD concentrations at two of the three activated sludge plants.

The type of pulping process showed no clear correlation with the TSS concentration, with the variations in repeat samples of the same mill being of comparable magnitude to the mill-to-mill variations. Sulfite mill 4 showed higher concentrations, but is not directly comparable to other mills because of high feed BOD concentrations and the previously noted sludge wasting practices.

The lowest TSS levels were observed at mill 2, a bleached Kraft mill with high water use per ton of production. This is also the newest of the mills tested, and was designed with extensive flow segregation and spill control facilities.

VOLATILE SUSPENDED SOLIDS (VSS)

The percent VSS for each mill effluent sample is shown on Figure 11. VSS averaged 80 percent or greater for all but two of the mills tested. VSS percent ranged from a low of 58 percent for mill number 8 to a high of near 100 percent for mills number 7 and 9. Mill number 8 is the only one that produces coated papers. Mill 9 operates a relatively high rate activated sludge system with very low levels of influent TSS, with the result that effluent TSS should be nearly all biologically generated. The reason for this high percent volatile content at mill 7 is unclear; it differs from mills 1 and 3 primarily in its location (south) and pulpwood species.

The lower average VSS present at mill 8 may be related to the presence of a flocculating clarifier following the two stage lagoon, which is used to separate and recycle solids to the head end of the lagoon. Also, heavy clay and titanium dioxide usage occurs at mill 8 due to grades manufactured. Mill 6 operates a fairly long sludge-age activated sludge process, runs some coated grades, and also returns silt from the raw water treatment clarifiers to the primary clarifier. These factors may explain the lower volatile content at mill 6.

BOD/TSS RELATIONSHIP

Figure 12 shows BOD per unit TSS data for each of the mill samples.

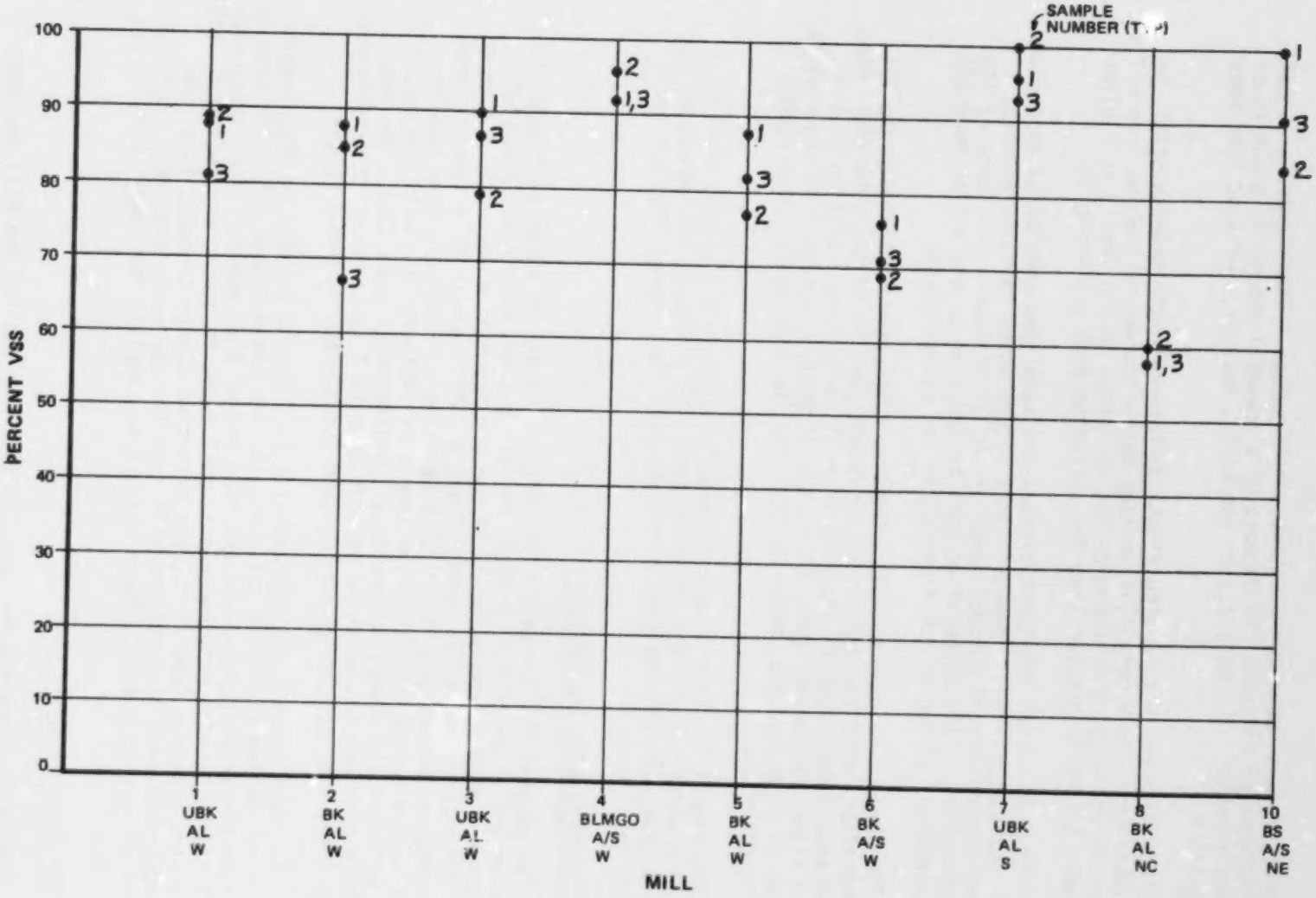


Figure 11
PERCENT VOLATILE SUSPENDED SOLIDS

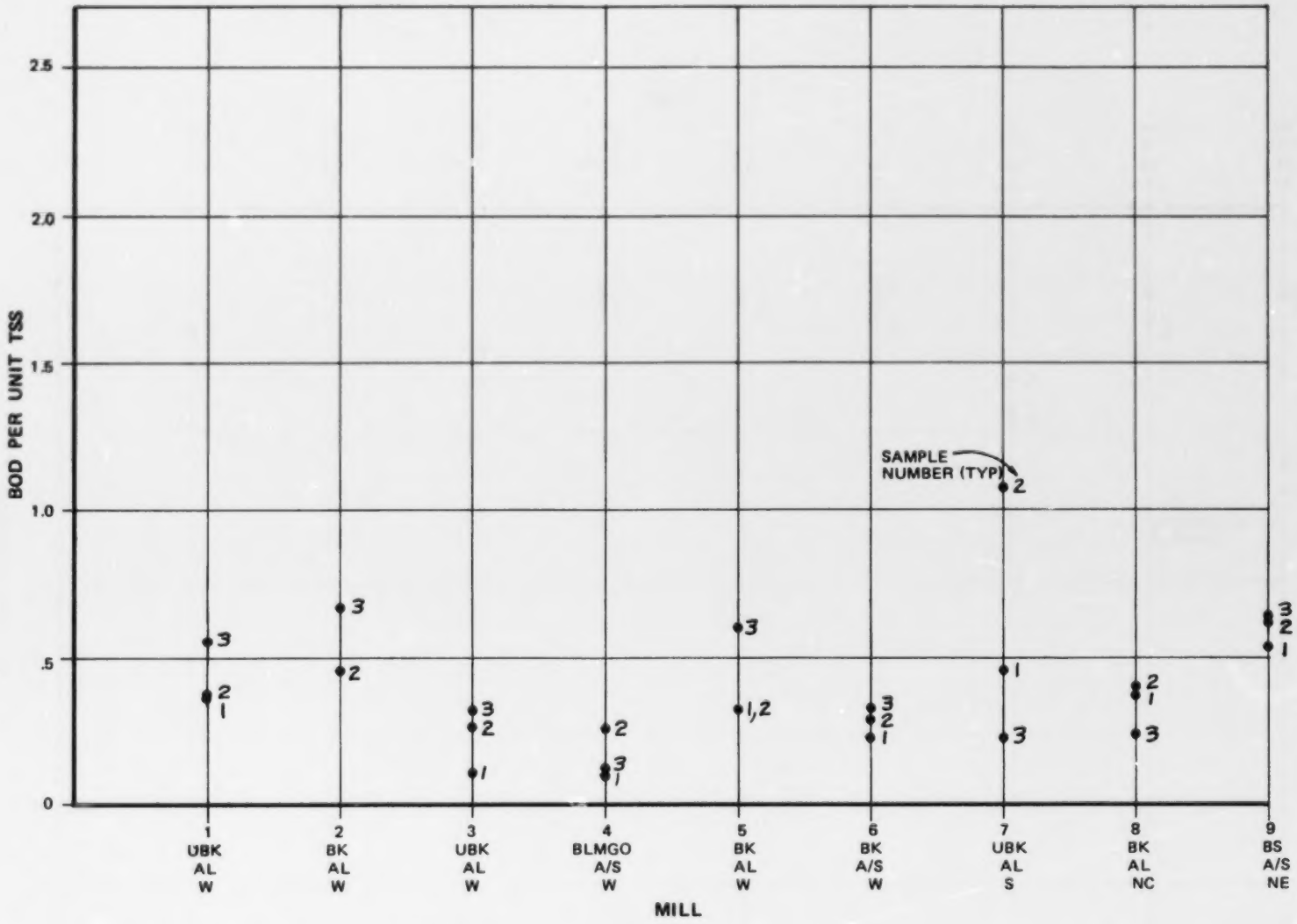


Figure 12
BOD CONTENT OF SOLIDS

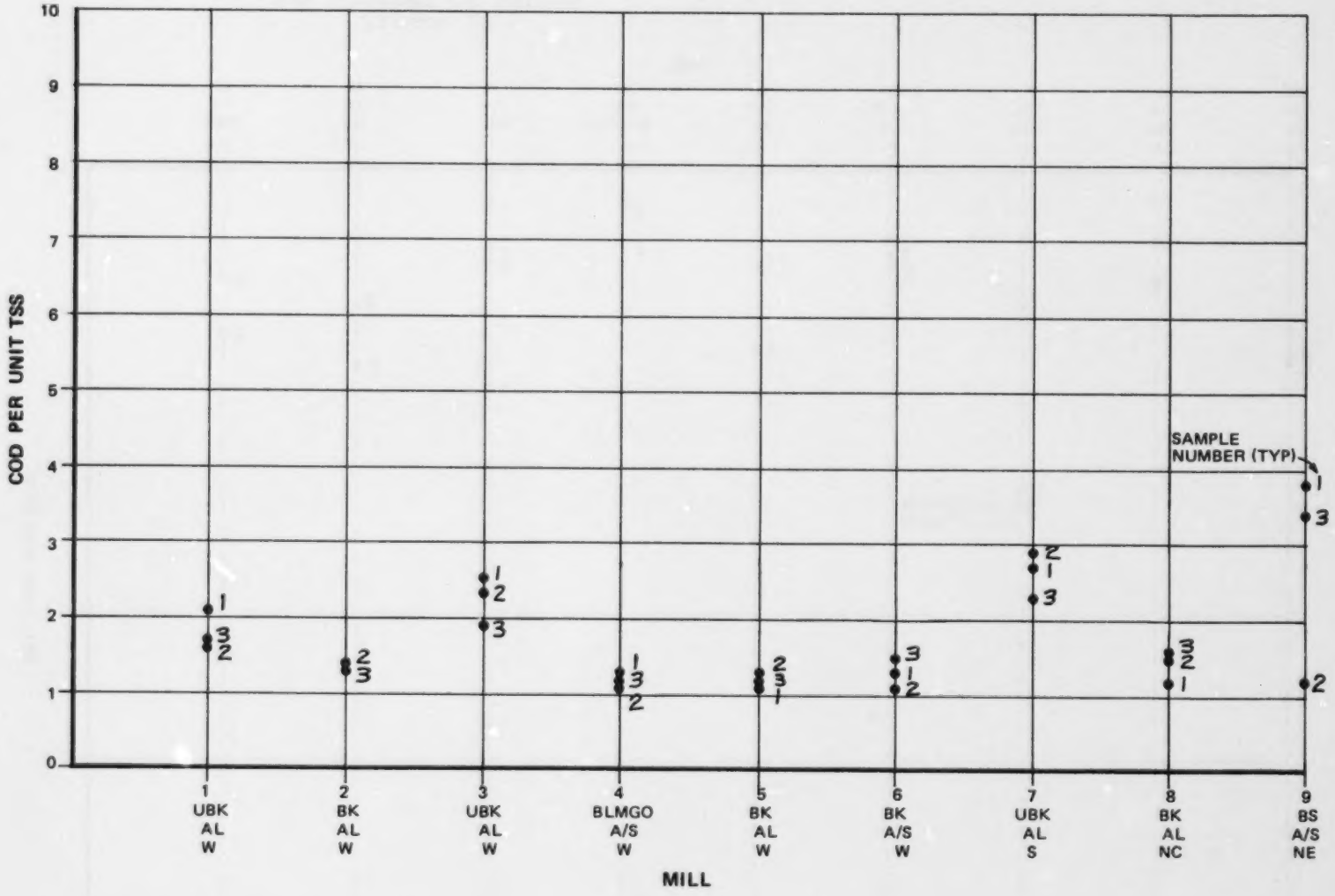


Figure 13
COD CONTENT OF SOLIDS

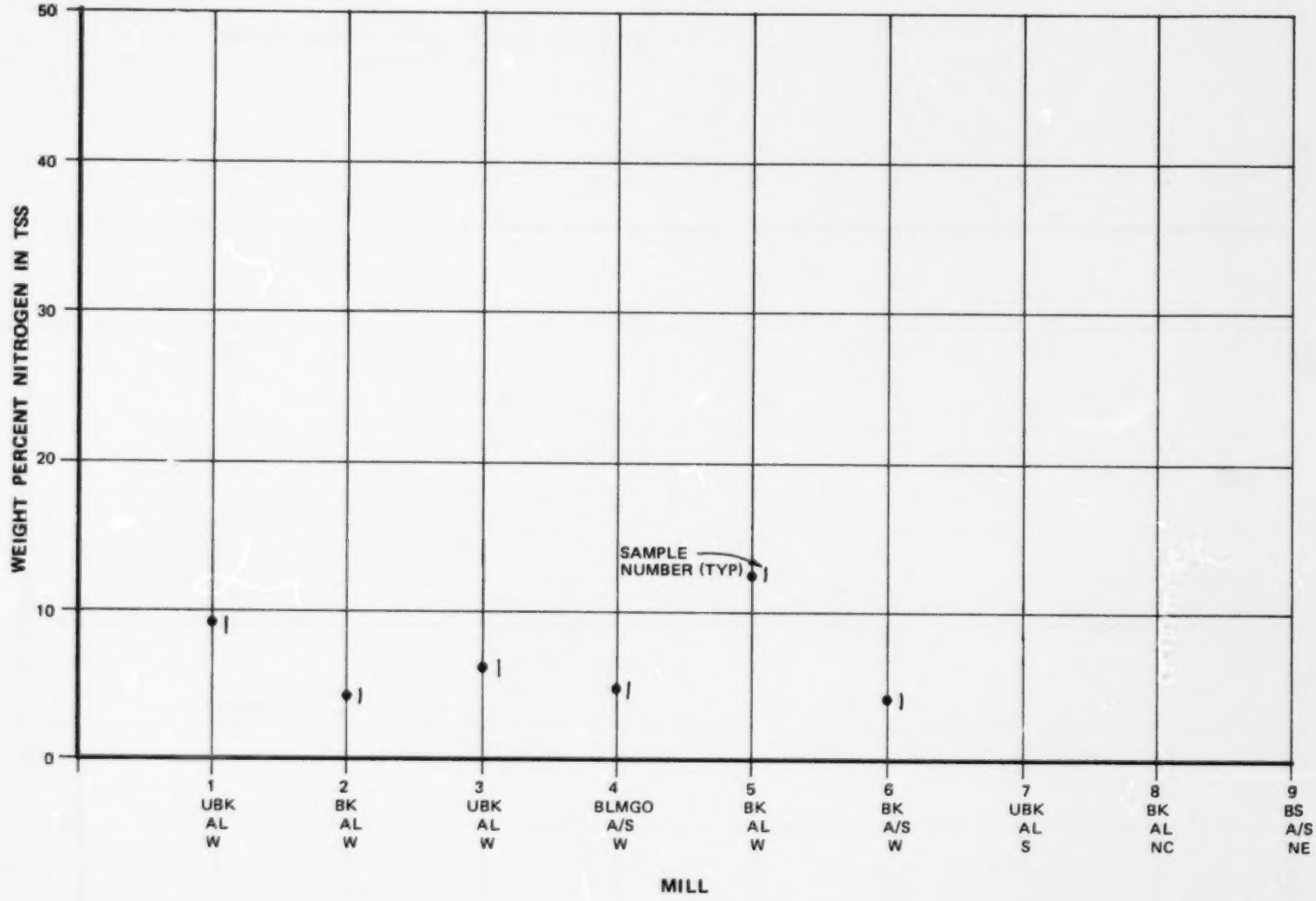


Figure 14
NITROGEN CONTENT OF SOLIDS

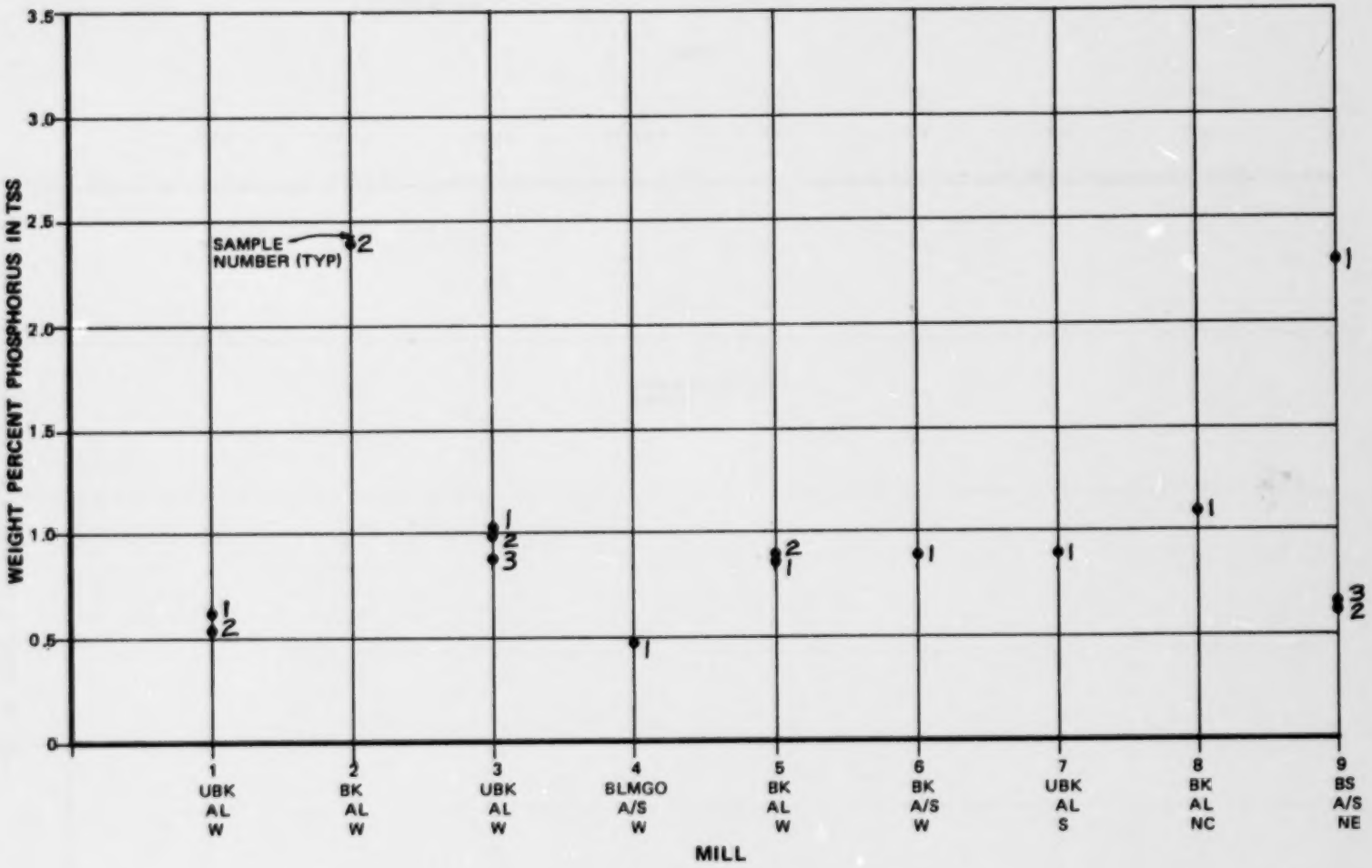


Figure 15
PHOSPHOROUS CONTENT OF SOLIDS

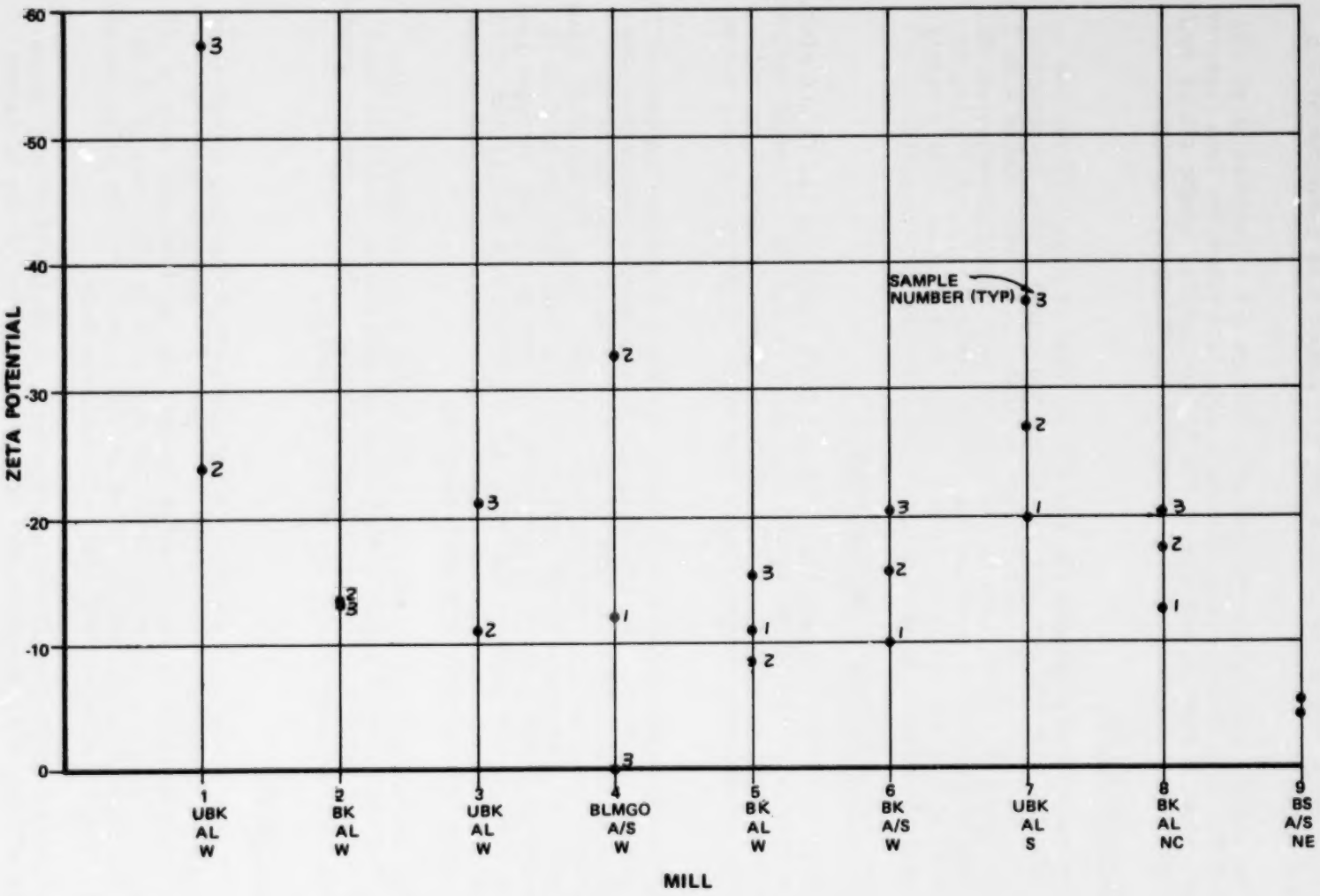


Figure 16
PARTICLE CHARGE CHARACTERISTICS

These data range from a low of 0.16 for mill number 4 to a maximum of 0.6 for mill number 9.

The overall average for BOD per unit TSS was 0.4. Correlation of BOD per unit TSS with sludge age (activated sludge) and retention time (aerated lagoons) shows a general decrease in the BOD per unit at longer sludge age/ retention times, except for mill 3 which did not follow this pattern.

COD/TSS RELATIONSHIP

The relationship between COD and TSS is shown on Figure 13 for the mills studied. The COD per unit TSS values indicate a highly carbonaceous material. Average COD per unit TSS varies from 1.2 for mill number 4 to 2.8 for mill number 9. Comparison of the unit BOD with unit COD indicates that a considerable quantity of material not readily biologically oxidizable, is present in all of the effluents tested. These data also indicate a fairly consistent correlation between unit BOD and unit COD for the solids.

NUTRIENT CONTENT (NITROGEN AND PHOSPHOROUS)

Total Kjeldahl Nitrogen (TKN as N) and total Phosphate (as P) are plotted as a percentage of the TSS by weight on Figures 14 and 15. Nitrogen content ranged from about 4 percent for mill number 6 to over 12 percent for mill number 5. Phosphorous content ranged from about 1/2 percent to over two percent.

Newly-generated bacterial mass typically shows a nitrogen content of 11 to 12 percent by weight. As the bacterial mass undergoes respiration, the average percent by weight nitrogen of the mass decreases because of the accumulation of polysaccharide cell wall residues. Thus, the observed nitrogen content of a mixed bacterial culture having a mean cell age of 6 to 10 days would be of the order of 9 percent N. On this basis, the nitrogen tests suggest that, on the average, the majority (approximately 75%) of the solids are biological. The nonbiological fraction could be as high as 50% at some mills, based on the individual mill test data.

The phosphorous content of biological solids averages about 1/5 the nitrogen content, which suggests that observed phosphorous levels in the 2 weight percent range would represent whole biomass. The test results support the view that the observed TSS are mainly biological.

PARTICLE CHARGE

Particle charge was determined by measurement of the Zeta Potential of the samples. These data are plotted on Figure 16. Negative particle charges were observed in every sample tested, ranging from near zero to -57 millivotls. However, the majority of the data were in the range of -5 to -20. The negatively charged particles provide a basis for the effective use of the trivalent aluminum and iron salts as coagulants.

There was no apparent correlation between particle charge and concentration of TSS, which suggests that particle dispersion is due to causes

other than simple charge repulsion. Limited observations of charge stabilization by coagulant addition bears out the hypothesis that production of an isoelectric charge condition will not insure effective coagulation and separation.

It is of interest to note that the third sample collected at mill 4 showed neutral particle charge, and that this sample contained several hundred mg/l of settleable solids. As noted previously, this is representative of an upset condition in which stable biofloc was carrying over the secondary clarifier weirs.

PARTICLE SIZE

Figure 17 is a plot of the mean particle size data for the nine mills. All data shown on this figure were obtained by the microspic direct count method. The mean particle size for the majority of the samples was between 0.5 and 1.5 microns.

At attempt was made to refine the particle sizing by use of the Coulter Counter. Samples from mills number 1, 2, and 3 were analyzed by this method, using equipment made available by the EPA laboratory in Corvallis. Both sizing methods resulted in similar mean particle size data for all three mills. However, the Coulter Counter method was subject to significant electrical interference in the size range below about 0.5 microns. Results of analyses performed simultaneously by the EPA laboratory and Coulter Electronics, on a split sample, however, confirmed the accuracy of the data from the EPA laboratory. Typical plots of particle size distribution by the direct count method are included in Appendix C (Figures C-1 through C-9).

Unfortunately, the analytical techniques did not allow determination of the particle size distribution by weight, which is of more significance with respect to tertiary solids removal. It is possible that the weight fraction greater than, say, 5 to 10 microns would correlate with percent removal by tertiary filtration. More research on particle size distribution by weight is needed to explore the possibility of predicting removal efficiency, and testing the efficiency of coagulation to create a more favorable size distribution for effective removal.

Based on the results reported here, a major quantity of the post biological solids are less than a few microns in mean diameter, and will likely require coagulation to be removed by physical methods.

STORAGE EFFECTS

Since some of the samples analyzed in this study were kept in refrigerated storage for a period of up to a few days during shipment, it was of interest to determine if storage significantly affected the solids' properties. Analyses were performed on fresh samples and compared with those on samples stored under refrigeration for a period of 5 days. Figures 18 through 23 are plots of the comparative data for mills number 1, 2, and 3. The various fresh and stored sample data are plotted so that "no difference" is represented by the solid diagonal line on the graphs. A consistent trend of data

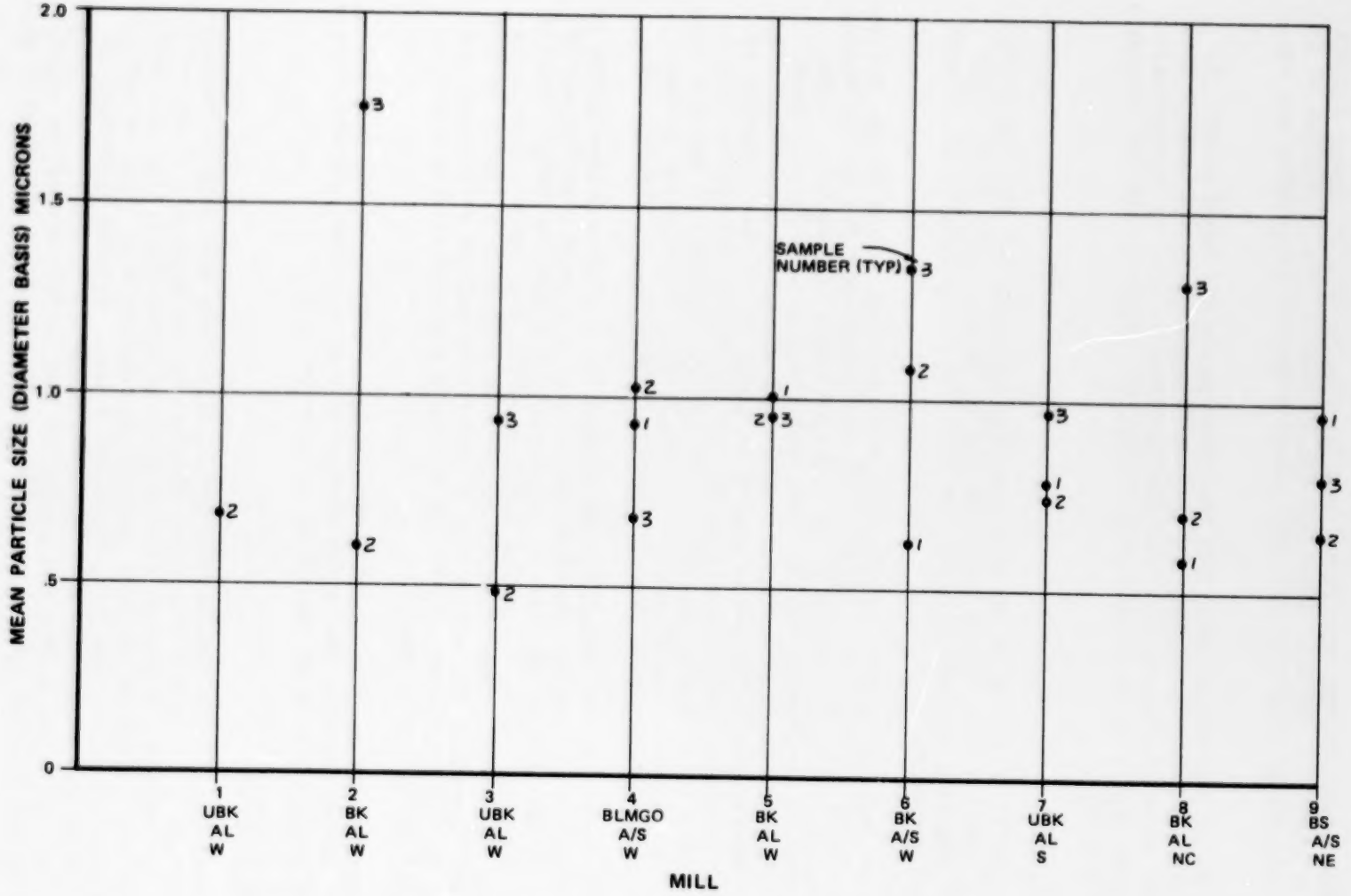


Figure 17
MEAN PARTICLE SIZE - DIRECT COUNT METHOD

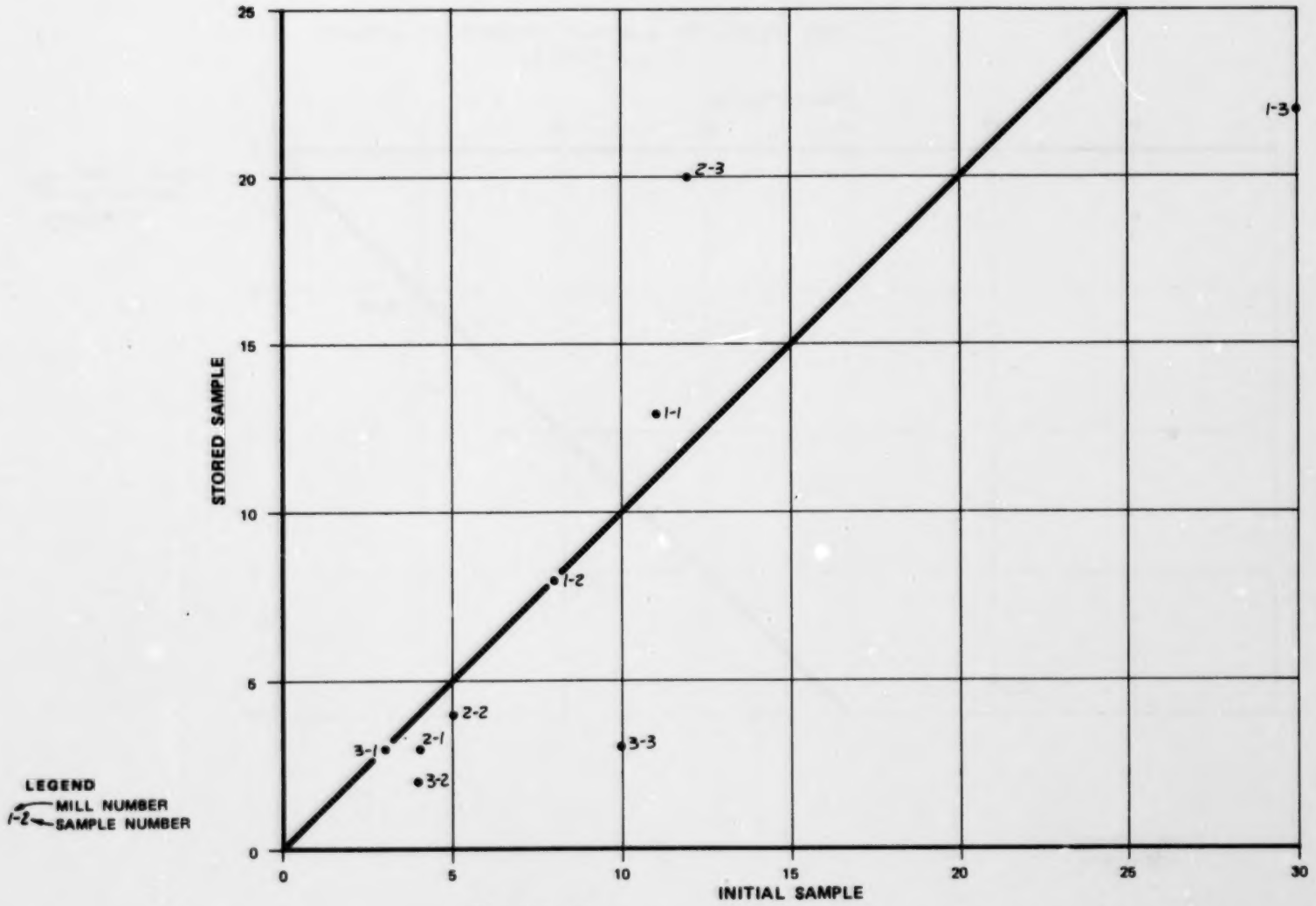


Figure 18
EFFECT OF SAMPLE STORAGE ON FILTERED BOD

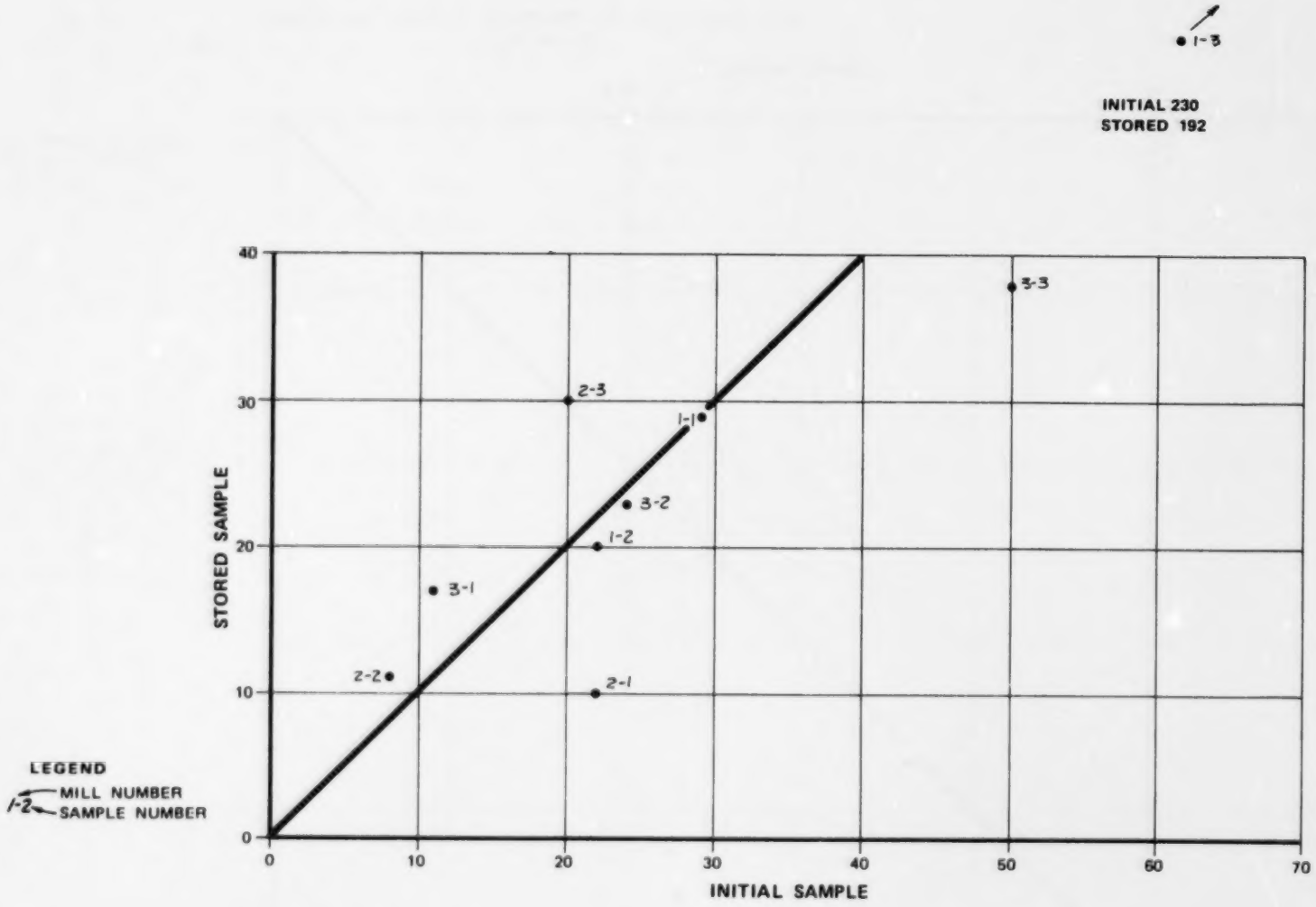
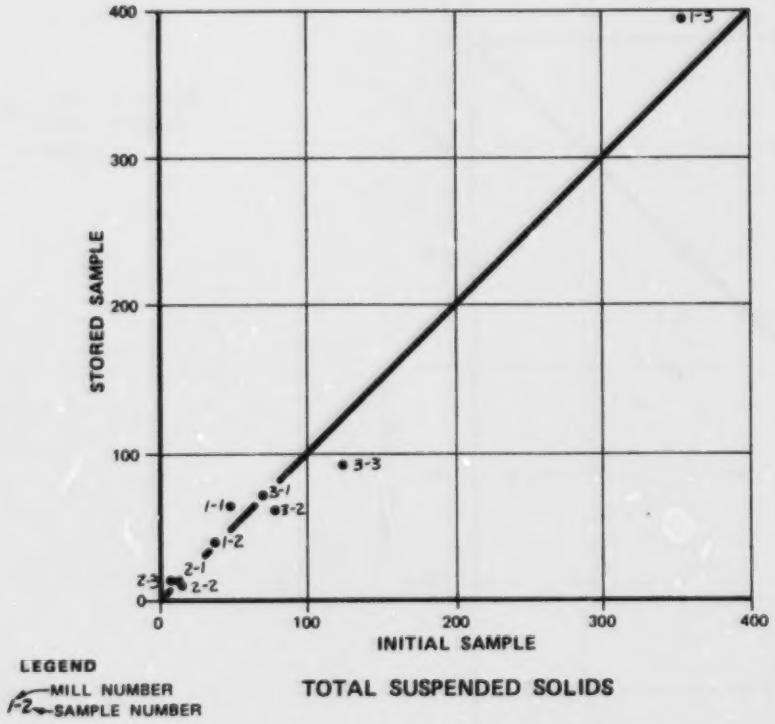
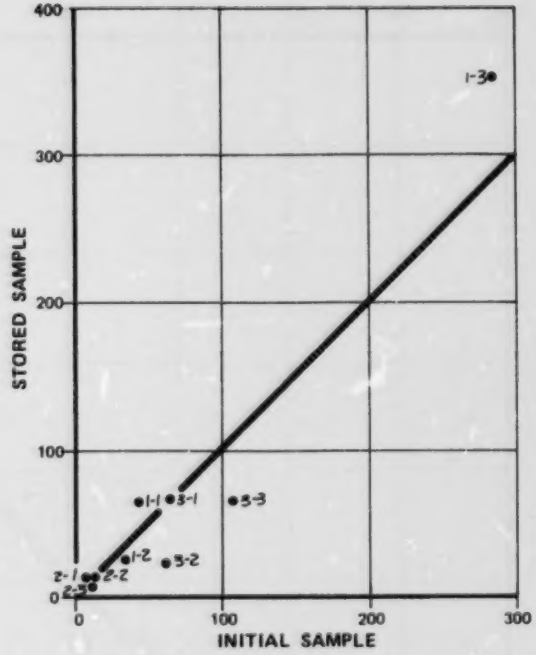


Figure 19
EFFECT OF SAMPLE STORAGE ON TOTAL BOD



TOTAL SUSPENDED SOLIDS



VOLATILE SUSPENDED SOLIDS

Figure 20
EFFECT OF SAMPLE STORAGE ON TOTAL AND
VOLATILE SUSPENDED SOLIDS

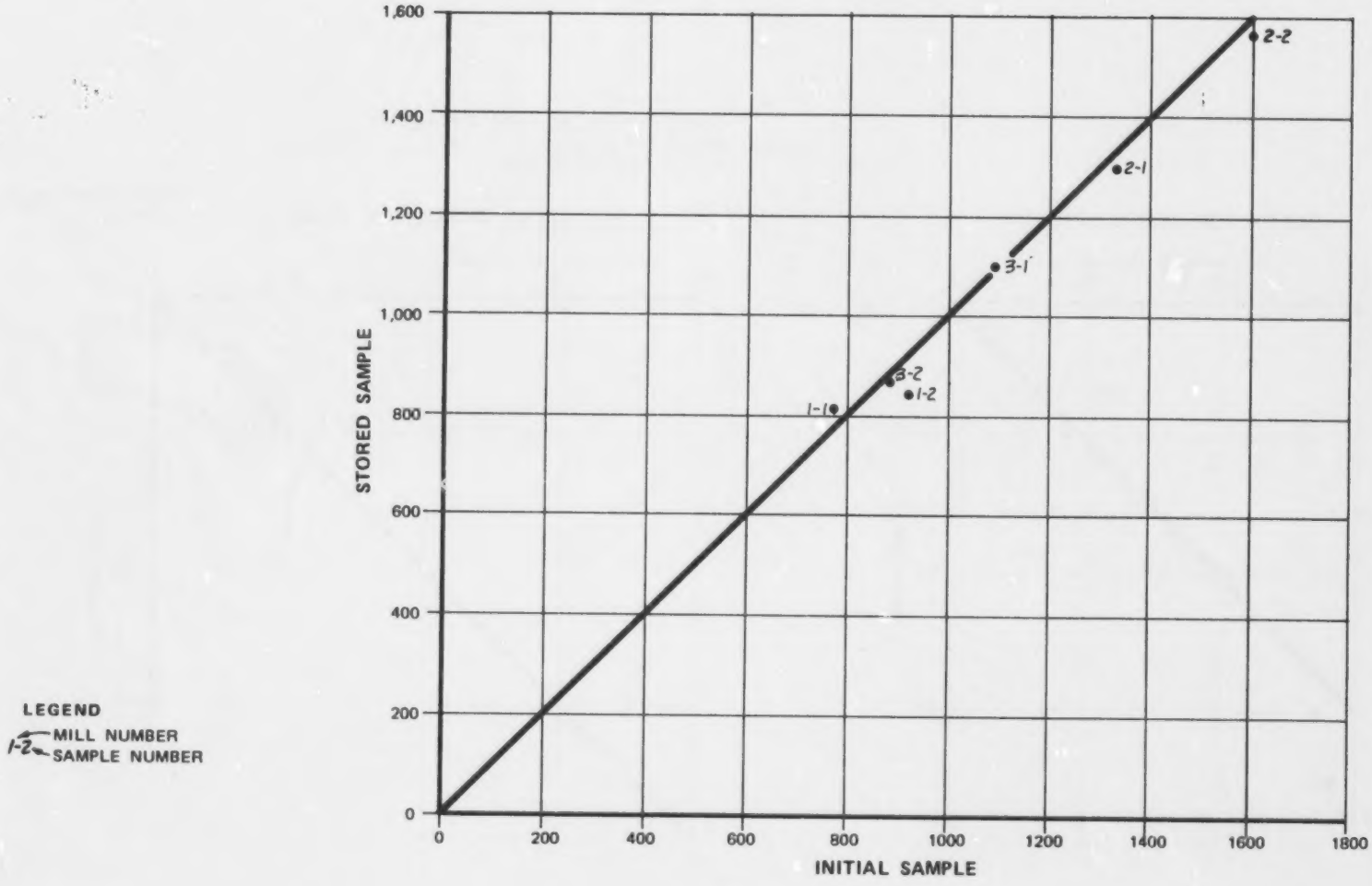


Figure 21
EFFECT OF SAMPLE STORAGE ON TOTAL SOLIDS

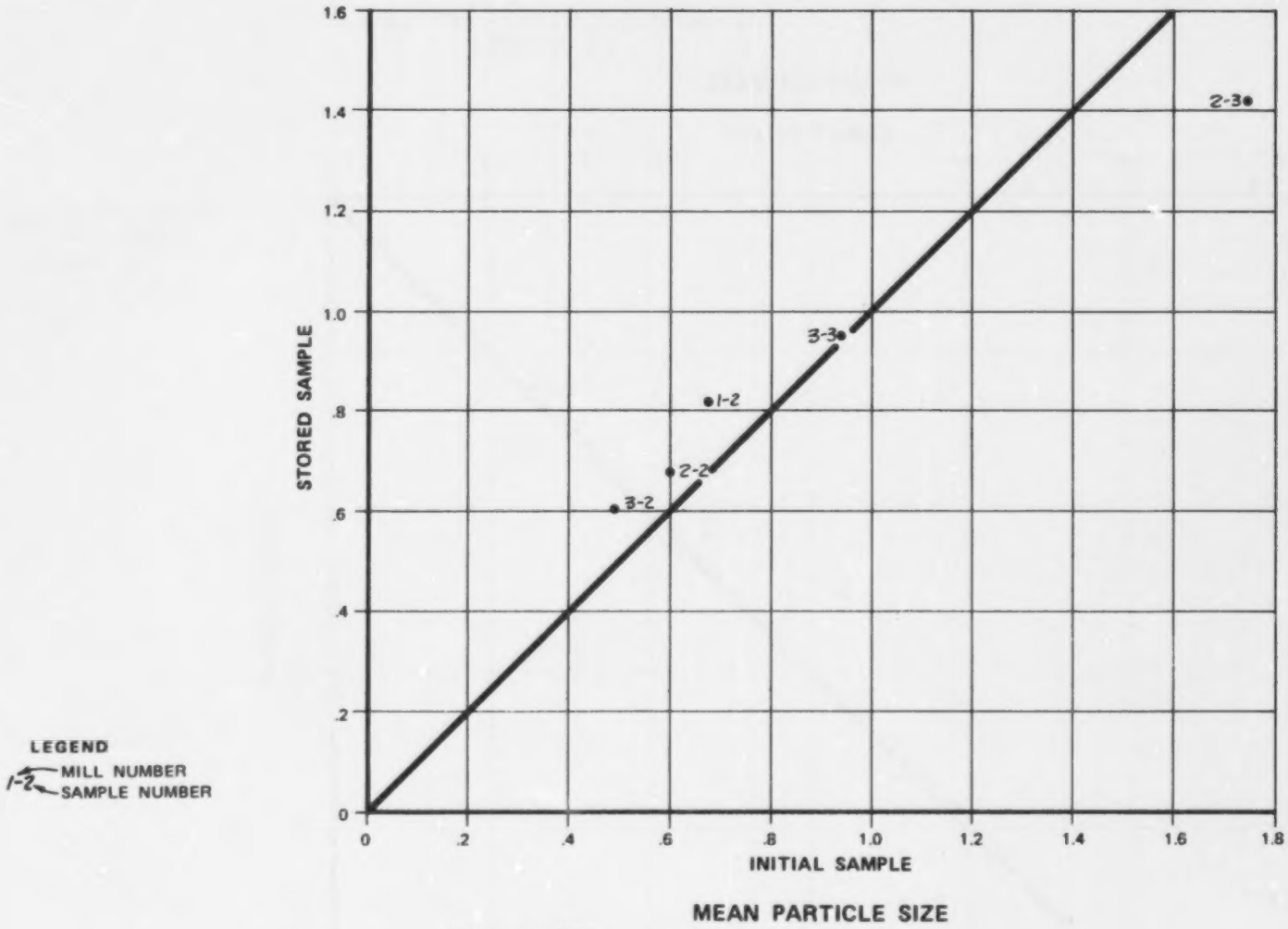


Figure 22
EFFECT OF SAMPLE STORAGE ON
MEAN PARTICLE SIZE

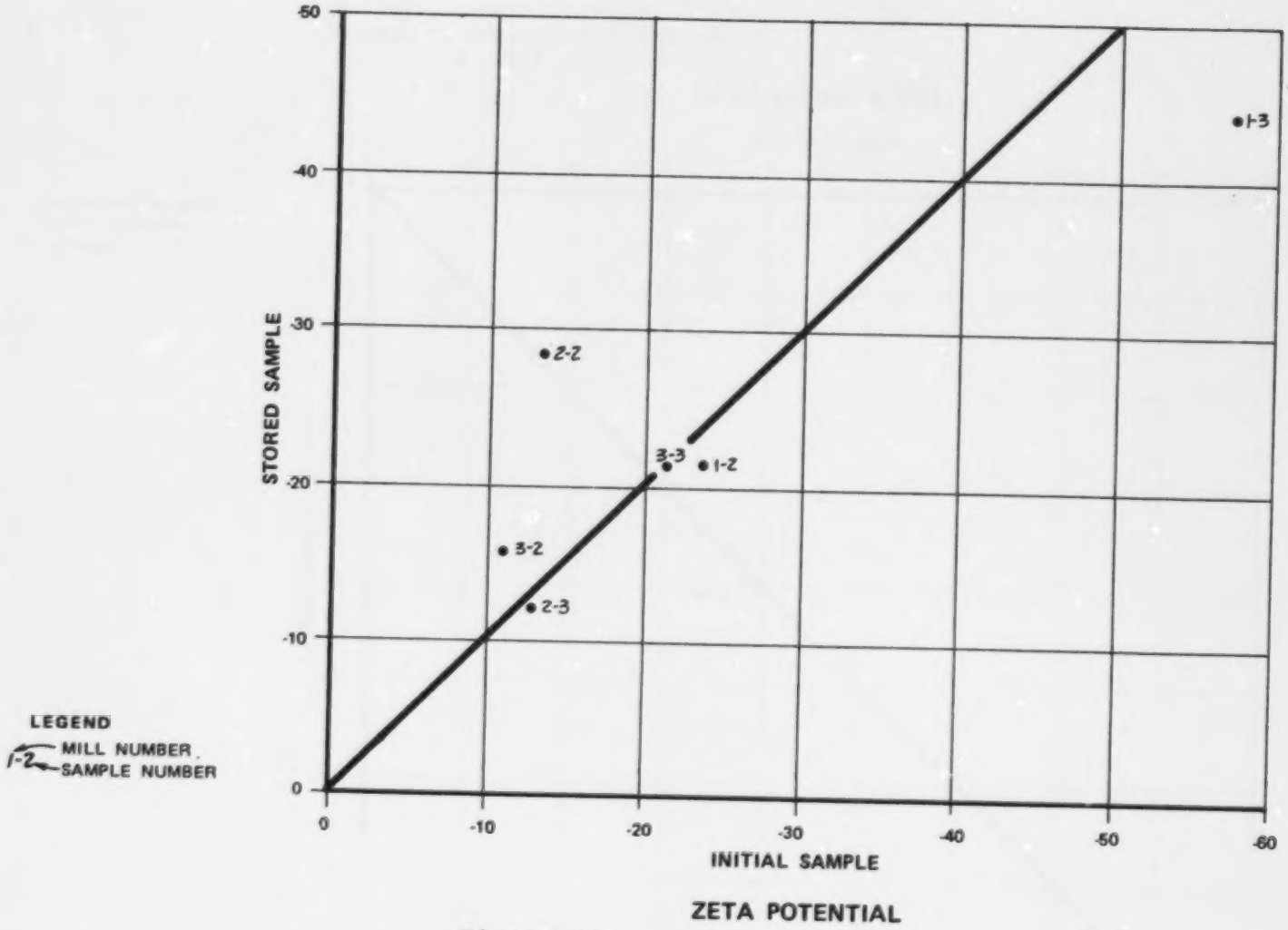


Figure 23
EFFECT OF SAMPLE STORAGE ON
PARTICLE CHARGE

points above or below the diagonal would indicate a storage effect. These figures show no consistent significant differences resulting from 5-day refrigerated storage of the samples, when compared with fresh 24-hour composite samples.

An additional comparison was made to determine the effect of 24-hour refrigerated storage of a composite sample (during the sampling period) on suspended solids concentration in comparison to grab samples collected over the same period. Four samples of aerated lagoon effluent were taken at different times during a 1-day period at mill 1. Each sample was immediately analyzed for total suspended solids (TSS), and the remaining portion stored to make up a composite sample for the day. The composite sample was also analyzed for TSS. Table 2 lists the average of five replicates for each sample, with standard deviation shown in parentheses.

TABLE 2

24-HOUR REFRIGERATED STORAGE EFFECTS

Sample No.	TSS (mg/l)	
	average	std. deviation
1 (8:00 a.m.)	111	(10.11)
2 (12:30 p.m.)	104	(8.94)
3 (4:30 p.m.)	119	(9.89)
4 (8:00 p.m.)	108	(7.30)
composite	101	(8.69)

These data provide no conclusive evidence of changes in suspended solids concentration due to natural coagulation during 24-hour composite sampling storage. The general tendency of the solids to blind the filter media before accumulating sufficient TSS for accurate weighing contributes to the fairly high standard deviation on replicate samples. As a result, the variation in individual TSS determinations overshadows any differences between the grab and composite results.

Although no significant increase in TSS due to natural coagulation was observed during this test, subsequent observations of settleable solids at the same mill suggest that some changes in solids characteristics may in fact occur during compositing. Grab samples placed in an Imhoff cone for 30 minutes showed zero to trace settleable solids, whereas the composite sample typically contains a noticeable amount of particulate deposit in the bottom of the container. This amplifies the need to base final conclusions regarding achievable TSS removals on pilot data collected on fresh rather than stored effluent.

METALS

Metal scans were performed on total and filtered samples using argon plasma emission spectrometry. This analytical technique was not sufficiently sensitive to allow determination of metals content of the post biological solids by difference (i.e., total sample minus filtered sample). As a result

no meaningful data are available on the metal content of the TSS.

Although the necessary sensitivity for determining weight-percent metals in the TSS was not achieved, there was no evidence of gross enrichment of metals on the TSS, such as might occur by adsorption on floc particles.

Metals content is an area which requires further research, since some researchers* have found evidence that a significant part of bleached kraft mill post biological TSS is a calcium-lignin precipitate. Further investigation of this hypothesis is needed. Particularly on the post biological TSS samples having low volatiles (high ash) content, further research on the makeup of the ash fraction is also needed.

MICROSCOPIC PHOTOGRAPHS

Several methods were investigated for preparation of samples to photograph. These included: light microscopy - wet mount; light microscopy - dry mount (with and without staining), phase contrast microscopy; and electron microscopy.

The wet mount method with the light microscope was not satisfactory because of the following limitations: A high magnification was required to make the small particles clearly visible, thus making it very difficult to focus on a sufficient number of particles at one time.

Electron microscopy was rejected due to problems resulting from preparation of samples with significant salt concentration. The salts crystalize during preparation, obscuring the solids particles.

Phase contrast microscopy was attempted, as well as dry mount without staining. However, dry mount with methylene blue staining appeared to provide the best material for photography. Photographs taken using this preparation method are shown on Figures 24 through 28.

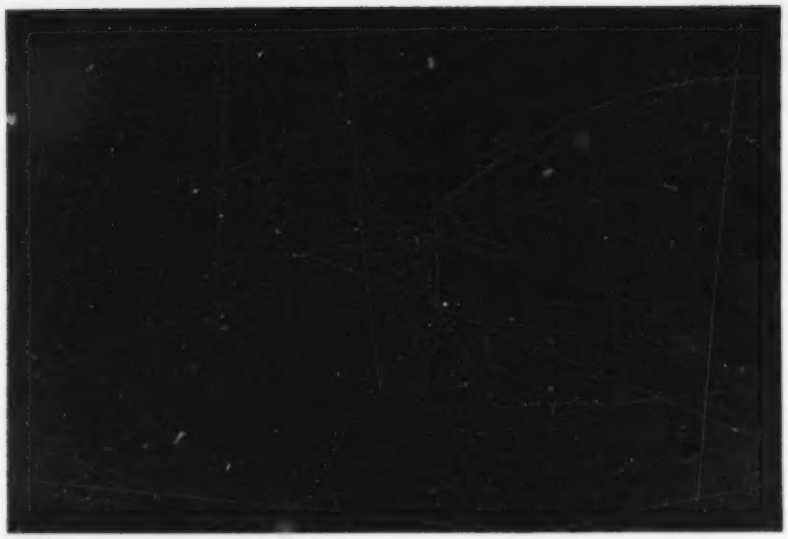
The photos show bacteria and some clumps of debris, but in general, do not indicate the presence of fiber type solids.

PHASE Ib - COAGULATION EXPERIMENTATION

GENERAL

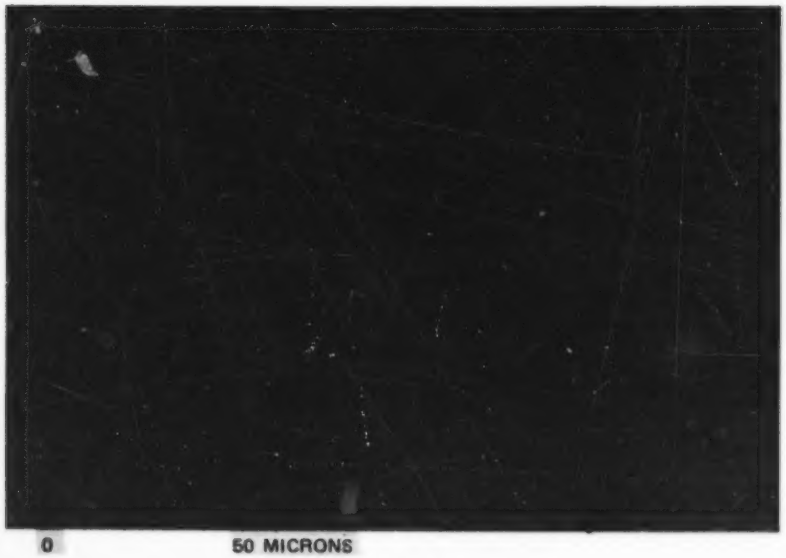
The purpose of this testing phase was to evaluate the effect of various conditioning chemicals on the effluent samples, and to select chemicals for use in the Phase Ic bench scale testing. The following chemicals were included in this evaluation:

* See British Columbia Forest Products, Ltd., CPAR Project Report 371-2; Origin and Removal of Precipitated Suspended Solids in Bleached Kraft Pump Mill Effluents, Sept. 30, 1976.



0 50 MICRONS

MILL NO. 1 – 450x
UBK-AL-W



0 50 MICRONS

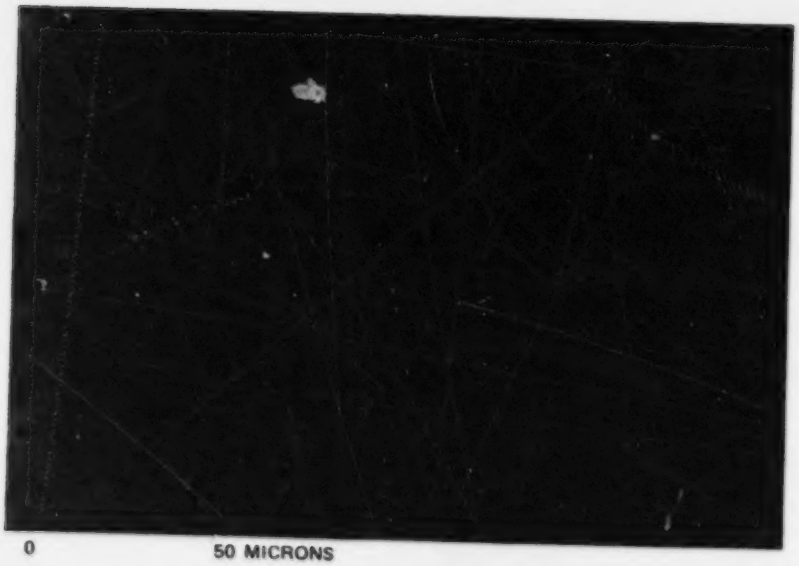
MILL NO. 2 – 450x
BK-AL-W

Figure 24 Secondary Effluent Solids

SAMPLE NO. 3

0 50 MICRONS

MILL NO. 4 – 450x
BMGO-AS-W



0 50 MICRONS

MILL NO. 5 – 450x
BK-AL-W

Figure 25 Secondary Effluent Solids

SAMPLE NO. 3

0 50 MICRONS

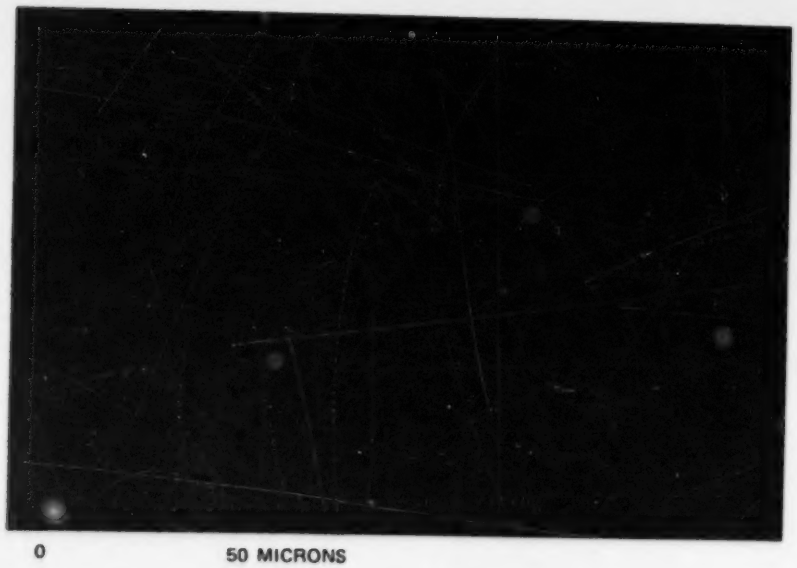
MILL NO. 6 – 450x
BK-AS-W

0 50 MICRONS

MILL NO. 7 – 450x
UBK-AL-S

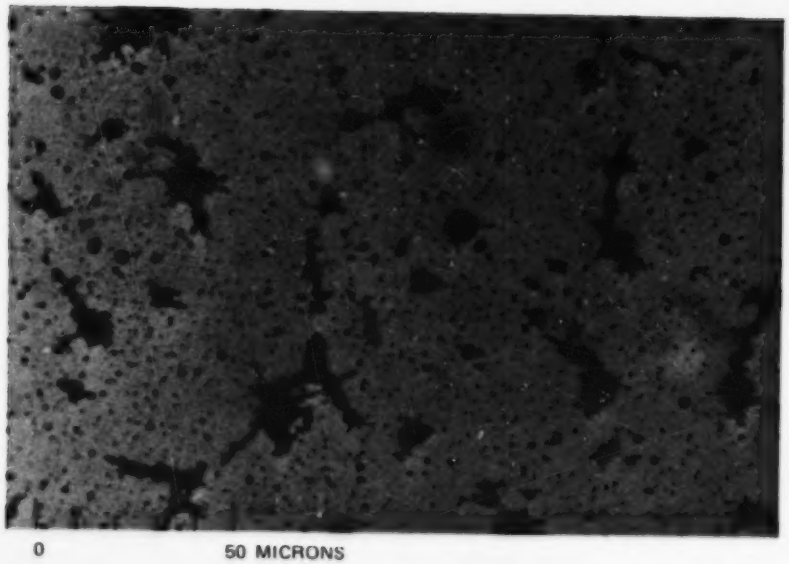
Figure 26 Secondary Effluent Solids

SAMPLE NO. 3



0 50 MICRONS

MILL NO. 8 – 450x
BK-AL-NC

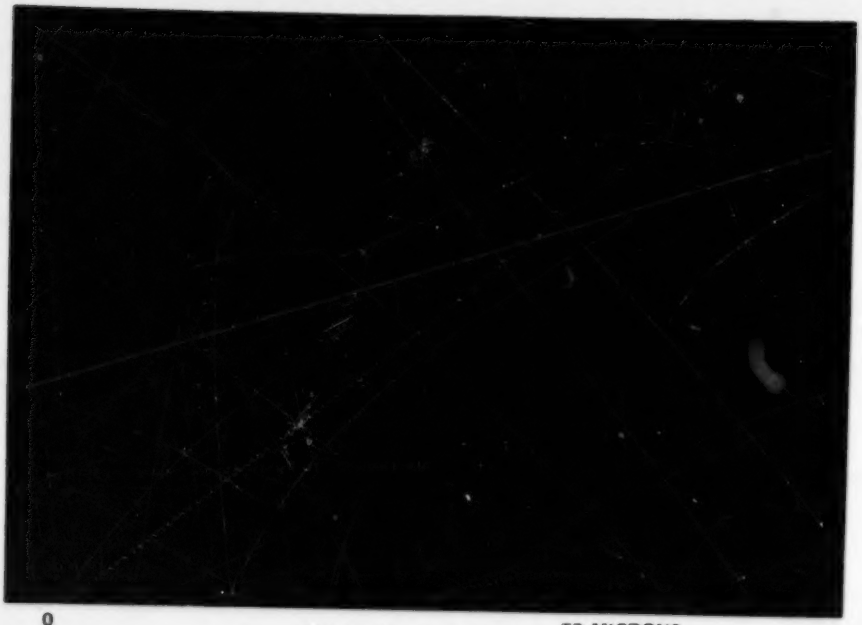


0 50 MICRONS

MILL NO. 9 – 450x
BNH_3-AS-NE

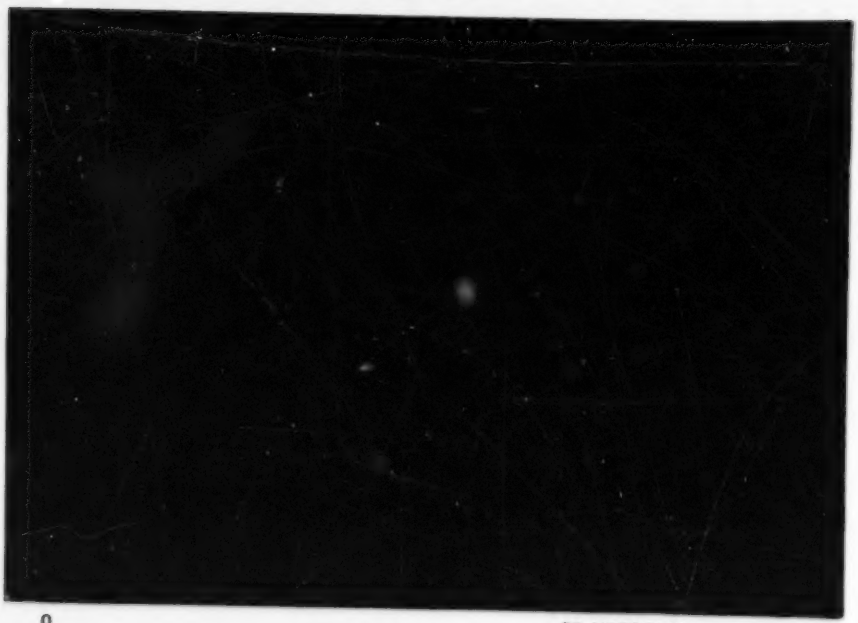
Figure 27 Secondary Effluent Solids

SAMPLE NO. 3



0 50 MICRONS

MILL NO. 4 – 1000x
BMGO-AS-W



0 50 MICRONS

MILL NO. 9 – 1000x
BNH_3-AS-NE

Figure 28 Secondary Effluent Solids

SAMPLE NO. 3

Inorganic Chemicals
- Alum
- Ferric Chloride
- Lime

Polymers
- Allied Colloids Percol 722
- Calgon WT-3000
- DOW Purifloc C-31
- Hercules Hercofloc 859
- Nalco 634

The comparisons were made with a jar-test apparatus, using samples from mills 1, 2, and 3. The general procedure for each sample was as follows:

- Each inorganic chemical was tested over a range of concentrations to determine the quantity required to produce adequate coagulation of the sample.
- A coagulant concentration was selected and used in conjunction with several different concentrations of the polymers listed.
- The best polymer and concentration for Phase Ic testing was selected from these tests, based on visual observation of floc formation and supernatant Total Suspended Solids (TSS) after settling.

RESULTS

Inorganic Chemicals

Table 3 lists the results of jar tests using alum, ferric chloride and lime. Six different concentrations of each chemical were used, but TSS data were obtained only for those concentrations which exhibited reasonable visual flocculation characteristics (i.e.: flocculation occured within 5 minutes with floc particles which separated rapidly).

TABLE 3

JAR TEST RESULTS
INORGANIC CHEMICALS

Chemical	Chemical Dose mg/l	Supernatant TSS (mg/l) Mill 1	Mill 2	Mill 3
Alum (as $Al_2(SO_4)_3$)	0	87	4	76
	40	-	-	62
	80	-	-	45
	120	77	61	-
	160	98	7	20
	200	56	5	-
	240	28	-	-
Ferric chloride	40	-	-	48
	120	80	-	40
	160	53	4	56
	200	47	0	38
	240	-	2	-
Lime	120	175	-	-
	160	-	11	-
	200	-	-	100

Concentrations of lime ranging from 40 mg/l to 240 mg/l resulted in very poor floc formation to no floc formation, and those concentrations tested showed an increase in supernatant TSS.

Ferric chloride additions in the range of 40 mg/l to 240 mg/l showed variable results. Mill 1 and 2 samples required about 200 mg/l of $FeCl_3$ to achieve a reasonable supernatant TSS level. The mill 3 sample produced good flocculation, but the floc tended to float to the surface.

Alum appeared to provide the most consistant flocculation and settling for all samples, and was selected for use with polymers. Alum also appeared to remove some color, basically in proportion to alum dosage.

Test runs involving varying pH during alum and ferric chloride coagulation showed no dramatic effect of pH in the range of pH 5-7. Terminal pH for the alum coagulation was in the range of 6 to 6.5 for all samples.

For the lime dosages tested, the terminal pH was 9.8 to 10.6 for those

samples with noticeable floc development. Higher lime dosages could have been used to induce massive precipitation (including color removal) but this approach was incompatible with the goals of this project.

Polymers

Selected polymers, at various concentrations were added, in conjunction with alum at a concentration slightly less than the minimum required to achieve maximum flocculation. Polymer concentrations of 1/2 mg/l through 8 mg/l were used in the jar test apparatus. The results of this testing are shown in Table 4.

TABLE 4

JAR TEST RESULTS - POLYMERS

Polymer	Polymer Concentration (mg/l)	Supernatant TSS (mg/l) Mill 1 (120 mg/l) Alum	Mill 2 (160 mg/l) Alum	Mill 3 (40 mg/l) Alum
Initial TSS	-	87	4	76
Calgon WT-3000	2	64	9	44
Hercofloc 859	3	100	11	64
Percol 722	2	64	13	-
	3	-	-	56
Nalco 634	2	-	-	48
	3	-	1	-
DOW C-31	2	-	13	-
	3	-	-	64

The data indicate that most of the polymers tested showed some improvement in the character of the floc, but none really stood out from the rest in terms of TSS removal.

Nalco 634 liquid polymer was selected for use in Phase Ic. Percol 722 powder showed comparable TSS removals, but 634 was chosen because the liquid was easier to work with and provided a more consistent stock solution for polymer addition.

APPLICATION

Jar tests were run on the samples obtained for Phase Ic testing to confirm the chemical concentration requirements. The results for mill 1 and 2 samples showed an optimum alum concentration of 100 mg/l (as $Al_2(SO_4)_3$). The

previous testing required 120 mg/l for the mill 1 sample and 160 mg/l for the mill 2 sample. Cursory testing indicated that this change could be due to a greater pH shift which is presumably the result of change in alkalinity of the samples. This also indicates a substantial variability in chemical addition requirements for these wastewaters.

Polymer concentration requirements appeared to be about the same as that used previously. Therefore, the concentrations were: 100 mg/l alum; and 2 mg/l Nalco 634 polymer for mills 1 and 2; 40 mg/l alum and 2 mg/l Nalco 634 for mill 3; and 180 mg/l alum and 2 mg/l Nalco 634 for mill 5.

Terminal pH for the samples tested in this study was in the range of 6 to 6.5 for all four mill samples. Evidence from the jar testing work suggests that chemical dosages and terminal pH will be variable at a given mill, and it is probable that a pH control system will be needed to maintain proper pH conditions in a commercial scale plant.

Testing of coagulation effectiveness by "freeness" measurements using the Buchner funnel and capillary suction time (CST) devices yielded mixed results for two reasons. First, the chemical conditioning produced increased TSS levels to the uncoagulated samples. Second, the wastewaters were sufficiently variable that repeat testing on the limited number of samples used in this study did not produce a reliable basis for comparison. For the extent of data available, the freeness tests showed no advantage over jar tests for coagulant optimization. It is possible that extensive testing at a specific mill site would yield a useful technique that is easier and faster than jar testing, but a larger data base is needed to refine these techniques.

PHASE Ic - SOLIDS REMOVAL TECHNIQUES

GENERAL

Bench scale tests were run on four samples using the following six solids removal techniques: Mixed media filtration; air flotation; microstraining; coagulation/sedimentation; sand filtration; and magnetic separation. Tests were run with and without chemical conditioning. Table 5 lists chemical conditioning used in these studies.

TABLE 5

CHEMICAL CONDITIONING

Mill	Alum Dose mg/l as $Al_2(SO_4)_3$	Polymer Dose mg/l Nalco 634
1	100	2
2	100	2
3	40	2
5	180	2

Figure 29 is a bar diagram showing the relative solids removal efficiency of each method, for each of the four mills. This figure shows that mixed

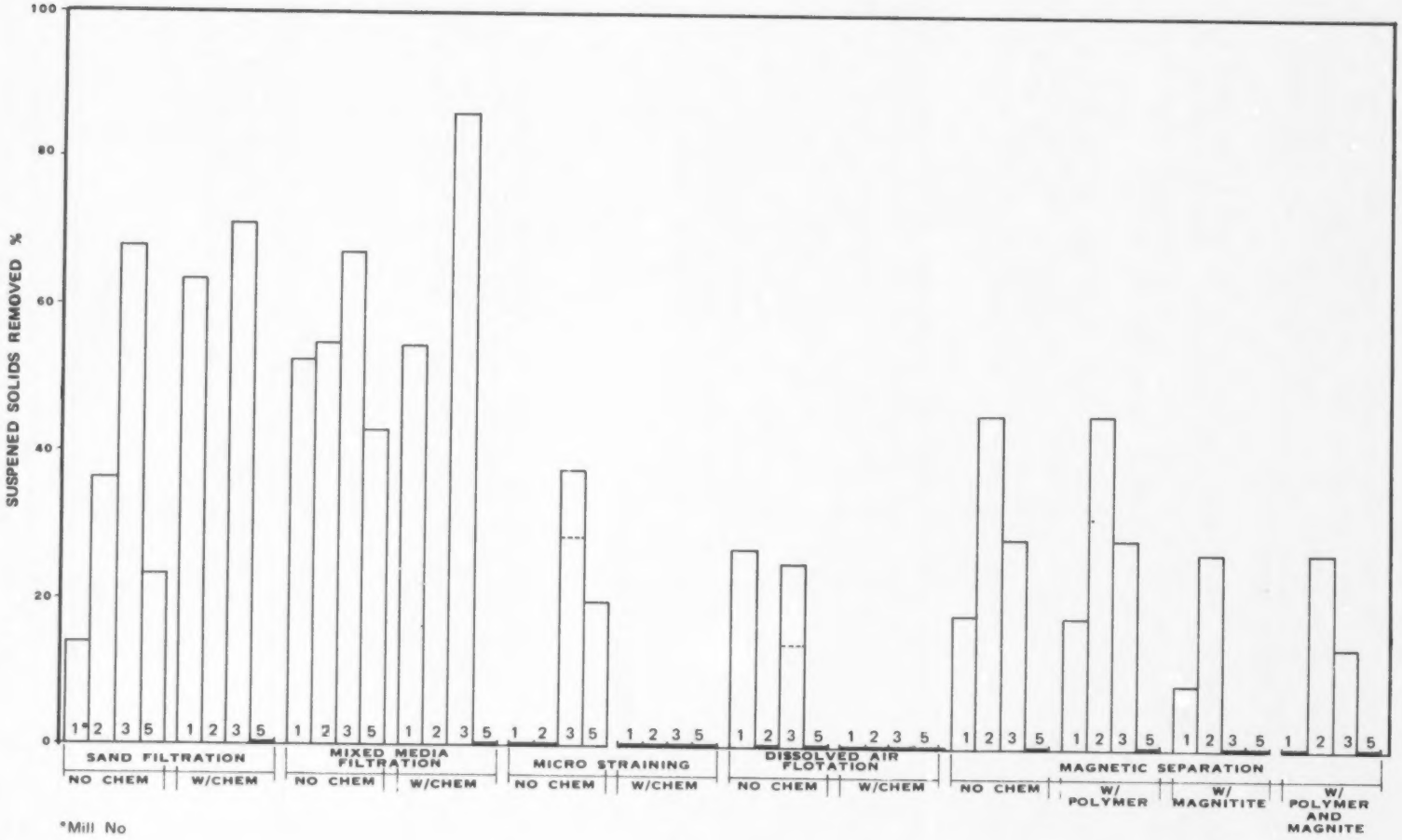


Figure 29
SUSPENDED SOLIDS REMOVAL EFFICIENCY

media filtration and sand filtration appear to be the most promising removal methods.

The results of these bench scale tests are discussed in the remainder of this chapter.

MIXED MEDIA FILTRATION

Media Evaluation

The initial tests relative to mixed media filtration consisted of evaluation of the various media to determine the optimum grain sizes and quantities to use for the actual testing. Table 6 lists suggested media combinations obtained from a manufacturer of mixed media filtration systems.

TABLE 6

SUGGESTED MEDIA COMPOSITION

Material	Grain Size	Depth*
Standard		
Ilmenite	0.2 mm	1 in.
Sand	0.4 mm	3 in.
Coal	1.1 mm	6 in.
Fine		
Ilmenite	0.2 mm	3 in.
Sand	0.4 mm	3 in.
Coal	1.1 mm	4 in.
Coarse		
Garnet	0.5 mm	1 in.
Sand	0.9 mm	3 in.
Coal	1.5 mm	6 in.

* Fine media at top of column and coarse material at bottom.

Two runs were made (mill 1 effluent, without chemical addition) using each of the media combinations listed in Table 6. The resultant total suspended solids (TSS) removals are listed in Table 7.

TABLE 7

SUGGESTED MEDIA FILTRATION RESULTS

Media	TSS Removal (%)
Standard	14
Fine	11
Coarse	14

Two runs were then made using modifications of the standard and fine media to try to improve TSS removal. Table 8 lists the composition of these modified media.

TABLE 8

MODIFIED MEDIA COMPOSITION

Media	Grain Size	Depth	TSS Removal (%)
Standard			
Ilmenite	0.2 mm	1 in.	
Sand	0.9 mm	3 in.	40
Coal	1.5 mm	6 in.	
Fine			
Ilmenite	0.2 mm	3 in.	
Sand	0.9 mm	3 in.	52
Coal	1.5 mm	4 in.	

On the basis of this testing, the modified fine media combination was selected for use in all subsequent testing.

Filtration Tests

All tests were run at a flow rate of approximately 100 ml/min. This resulted in a filter loading rate of about $3.4 \times 10^{-3} m^3/s/m^2$ (5 gpm/ft^2), based on the size of the filter column used. Changes in flow rate occurred on some runs as a result of the variation in solids content of the samples. The flow rate was measured periodically during each run.

Table 9 lists average results of mixed media filtration tests, with and without chemical addition, for effluent samples from the four mills.

TABLE 9

MIXED MEDIA FILTRATION RESULTS

Mill No.	Initial TSS (mg/l)	TSS Removal (%) W/Chemicals	W/O Chemicals
1	160	69	69
2	6	0	58
3	70	85	67
5	60	0	43

The poor TSS removal for mills number 2 and 5 resulted from a significant increase in TSS concentration with chemical addition, and failure of the filter to remove a quantity of solids as large as that added. Therefore, a net increase in solids was measured, based on the original TSS concentration in the sample.

The removal efficiency reported for mill number 2 is somewhat suspect because of the very low initial TSS concentration. A small change in TSS concentration would result in a major difference in removal efficiency. Chemical addition increased the TSS from the initial value of 6 mg/l to 200 mg/l. The filtrate TSS concentration with chemical addition was 16 mg/l showing a net increase.

A similar phenomenon occurred with the other samples. Mill number 1 TSS increased from 160 mg/l to 300 mg/l and for mill number 3 the increase was from 70 mg/l to 120 mg/l, with the addition of chemicals.

Additional samples from mills number 1 and 3 were secured and sent to a mixed media filter manufacturer for independent TSS removal evaluation. The tests were conducted using a continuous filtration apparatus with a sample volume of about $1.9 \times 10^{-3} m^3$ (5 gal). Both samples were run with a filter loading rate of about $3.4 \times 10^{-3} m^3/s/m^2$ (5 gpm/ft^2) without chemical addition.

TSS removal recorded by the manufacturer for mill number 1 averaged 30 percent and for mill number 3, 41 percent. The headloss increased at a rate of about 1.3 to 1.6 feet per hour. The manufacturer concluded that adding chemicals directly to the filter did not appear to be feasible because of the high solids loading. They also concluded that chemical treatment with settling prior to filtration might be required to improve filter efficiency.

DISSOLVED AIR FLOTATION (DAF)

Two runs were made on each sample at air/solids ratios of 0.06, 0.03 and 0.01, with extremely poor results. Most of the samples tested showed no removal at all. The only significant removals observed were on samples from mill number 3. Table 10 lists the DAF data (average of two runs).

MICROSTRAINING

Results of microstraining tests using a batch laboratory unit are presented in Table 11. Several different fabric mesh sizes were tested, ranging from 1 micron openings to 74 micron opening, both with and without chemical conditioning. In general, poor results were obtained. The fabrics tended to blind very rapidly, resulting in short filter runs. Only samples from mill number 3, without chemical addition, produced any significant TSS removals. The best removals were observed with the 74 micron openings, the largest tested. This was an unexpected phenomenon because particle size measurements showed that most of the solids were less than 2 microns in size. This condition may be the result of stapling and bridging effects of the solids on the strainer media.

TABLE 10

DISSOLVED AIR FLOTATION RESULTS

Mill	A/S Ratio	Final TSS w/chem	Final TSS w/o chem	TSS Removal (%) w/chem	TSS Removal (%) w/o chem
1 (110)*	0.06	145	100	--	9
	0.03	160	125	--	--
	0.01	170	110	--	0
2 (5.5)	0.06	100	7.5	--	--
3 (70)	0.06	40	60	43	14
	0.03	66	53	6	25
	0.01	113	53	--	25
5	0.06	152	60	--	0

* Initial TSS concentration.

TABLE 11

MICROSTRAINING RESULTS

Mill	Fabric	Final TSS w/chem	Final TSS w/o chem	TSS Removal w/chem	TSS Removal w/o chem
1 (110)*	35 micron	290	110	--	0
2 (5.5)	35 micron	190	12	--	--
	17 micron	220		--	
	21 micron		8		
3 (70)	74 micron	100	45	--	37
	35 micron	135	50	--	29
	21 micron	120	50	--	29
5 (60)	35 micron		64		--
	21 micron	330	60	--	0
	10 micron		48		20

* Initial TSS Concentration

COAGULATION/SEDIMENTATION

Settling column tests were run on samples from mills number 1, 2 and 3. Two columns were used and tests were run simultaneously, with and without chemical addition. No settling column tests were run on mill number 5 effluent because the volume required and the distance involved made shipping such a large sample under refrigerated conditions impractical.

Figure 30 is a plot of the settling data for the mill number 1 sample. This figure shows the relationship between TSS concentration at each column port and settling time, both with and without chemical addition. The settling was monitored by periodic sampling at each port over a 6-hour period.

These results illustrate the characteristic increase in TSS with chemical addition. They also show that, while settling was rapid during the first hour, the overall settling after six hours did not reach a TSS level as low as the concentration in the untreated sample. Therefore, it appears that chemical addition, at least the concentration used in this test run, was not beneficial in reducing the effluent TSS concentration.

With no chemical addition, the TSS concentration at all ports, after six hours settling, was essentially the same as the initial concentration.

Figures 31 and 32 are similar plots for mills number 2 and 3 respectively. These samples exhibited settling characteristics similar to those of mill number 1.

An attempt was made to develop a settling rate correlation between the three samples tested and the sample from mill number 5 because an inadequate quantity of sample for a settling column test was available for mill number 5. Jar tests were run simultaneously with the settling column test on samples from mills number 1 and 3. Similar jar tests were run on the sample from mill number 5. However, due to the poor settling characteristics of the solids, no trends were observed and no significant comparisons could be made.

SAND FILTRATION

Media Evaluation

Two runs each were made using fine sand (0.4 mm) and coarse sand (0.9 mm), and TSS removals were measured as a basis to select a media for use in the actual testing. No significant difference in TSS removal was observed between the two media grain sizes. The fine sand was selected for testing.

Filtration Tests

The sand filtration tests were run using the same filter columns as for the mixed media tests. The filter loading rate was approximately 3.4×10^{-3} $m^3/s/m^2$ (5 gpm/ft^2), which required a flow rate of about .100 ml/minute.

Table 12 lists average TSS removals for test runs on each sample, with

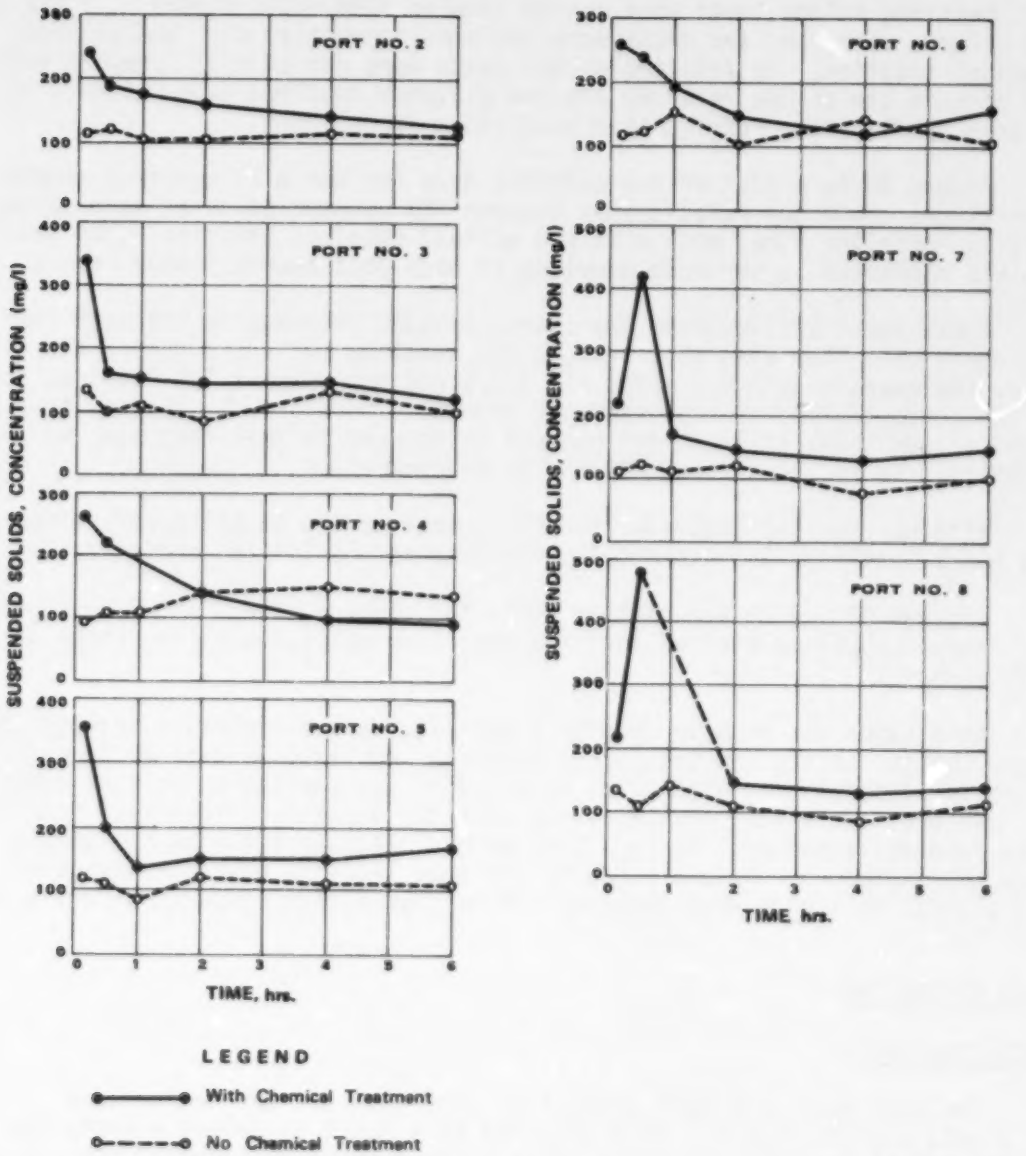


Figure 30
COAGULATION/SEDIMENTATION DATA MILL NO. 1

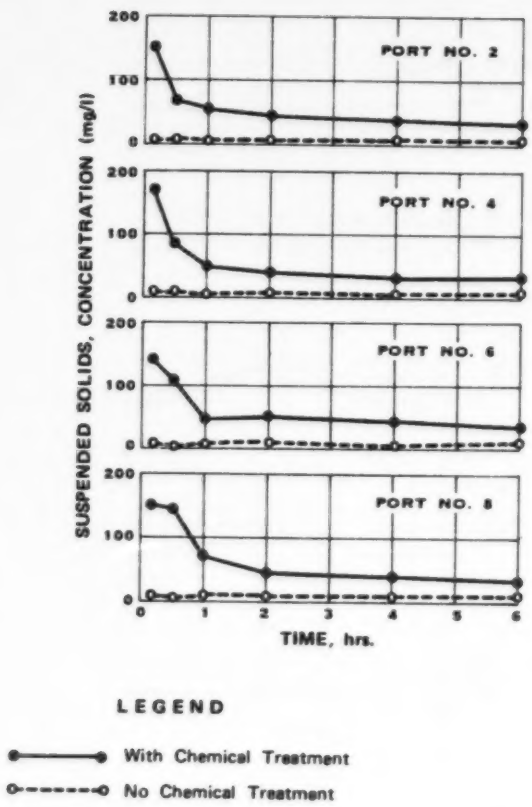


Figure 31
COAGULATION/SEDIMENTATION DATA MILL NO. 2

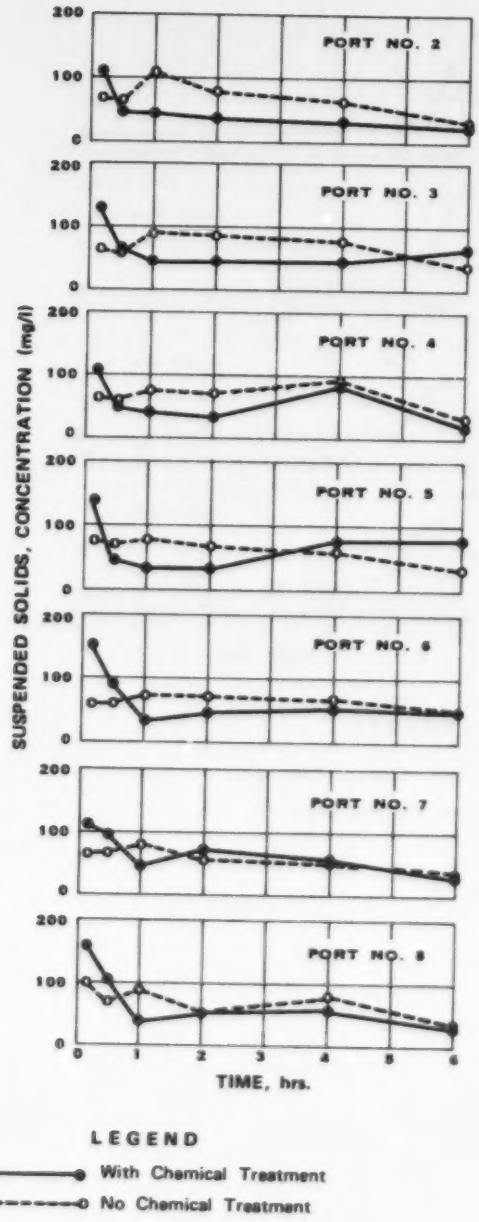


Figure 32
COAGULATION/SEDIMENTATION DATA MILL NO. 3

and without chemical addition.

TABLE 12

SAND FILTRATION RESULTS

Mill	Initial TSS (mg/l)	TSS Removal (%) w/chem	w/o chem
1	110	64	14
2	5.5		36
3	70	71	68
5	60		23

Mills number 2 and 5 showed no TSS removal with chemical addition, again, as with the mixed media filtration tests, due to the significant increase in TSS with chemical addition. These data indicate that, with the exception of mill number 1, there was no significant advantage to chemical addition.

MAGNETIC SEPARATION

Magnetic separation tests were run using a device called a Frantz Ferrofilter. This device operates on the basis that by placing the proper type of steel media into the magnetic field generated, concentrated magnetic force sites will be produced, which will tend to attract particles with a net charge. The flow rate through the filter was maintained at approximately 750 ml/minute for each run. Two different media were tested--packed steel wool and steel discs.

Several runs using steel wool media were made. The use of steel wool was discontinued after these runs for the following reasons: a review of the literature on magnetic separation revealed that steel wool is very difficult to magnetize because of its high void content, and the Ferrofilter does not have the capacity to generate the magnetic intensities needed to adequately magnetize steel wool; and the steel wool tended to act as a filter, thus, removing solids from the flow by physical rather than magnetic means.

Test runs included untreated samples, and those treated with polymer alone, magnetite alone, and a combination of polymer and magnetite. The concentration of magnetite added was varied for each sample to try to improve its function. The concentration added for mill number 1 was 3 times the TSS concentration; for mill number 2 was 2.5 times TSS; and for mill number 3 was 1 times the TSS concentration.

Table 13 lists the TSS removal data for mills number 1, 2, and 3. The data for mill number 1 includes both steel wool media and disc media tests. Steel wool media removal was greater than that of the discs because of the physical solids removal as discussed previously.

TSS removals for mill number 2 appeared to be reasonably good. However, these data may be misleading because of the very low TSS concentration in the

sample. As the table shows, a very small difference in TSS concentration results in a large change in percent removal.

In each case, TSS removal appeared to be better for runs with untreated samples or with only polymer addition. This is an indication that the addition of magnetite to the samples not only failed to improve TSS removal, but was detrimental to removal.

This condition was likely due to the failure of the suspended solids to strongly adhere to the magnetite. The magnetite being strongly magnetic in character, would be attracted to the media much more rapidly than the weakly-magnetic or non-magnetic suspended solids particles. This would likely have the effect of reducing the magnetic attraction for the suspended solids. Thus, even though the magnetite may have been completely removed from the liquid, fewer of the suspended solids would have been removed.

TABLE 13

MAGNETIC SEPARATION RESULTS

Mill No.	Run No.	Magnetite	Polymer	Effluent TSS (mg/l)	TSS Removal %
1 (110)[1]	1[2]	No	No	90	18
	2[2]	No	Yes	90	18
	3[2]	Yes	No	100	9
	4[2]	Yes	Yes	110	0
	5	Yes	Yes	100	9
2 (5)[1]	1	No	No	3	40
	2	No	Yes	3	40
	3	Yes	Yes	4	20
	4	Yes	Yes	4	20
3 (65)[1]	1	No	No	50	23
	2	No	Yes	50	23
	3	Yes	No	70	--
	4	Yes	Yes	60	8

[1] Initial TSS Concentration

[2] Steel Wool Media

OVERVIEW OF BENCH SCALE TEST RESULTS

In general, the bench scale testing showed several common elements. Attempts to chemically coagulate the TSS to facilitate removal were variable and - short of a massive chemical dose to induce full precipitation of both TSS and color - frequently resulted in net increases in effluent TSS. The fact that coagulants invariably increased the TSS levels before subsequent removal (e.g., filtration) is an important factor in determing the quantity of sludge for disposal. Sludge disposal quantities for the coagulated efflu-

ent may be several times the value calculated from the net change in effluent TSS. The generation of increased TSS through coagulation will also affect the commercial plant operating condition, for example, filter run times and backwash fines recycle.

The effluents were highly variable, from a standpoint of both mill-to-mill comparisons, as well as repeat observations at a given mill. To adequately define effluent TSS variability factors for a tertiary removal process will require on-site pilot testing over a period of at least several weeks. Furthermore, review of effluent monitoring data from some mills suggests that seasonal (temperature-related) changes in TSS levels may be significant, which indicates the need for "summer" and "winter" pilot data.

The low effluent TSS levels (10 mg/l TSS or less) commonly achieved in municipal secondary effluents were not achieved by even the best of the post biological solids removal process tested. (An exception is mill 2, where initial TSS levels before testing were normally 10-20 mg/l.) Because of the variability, it is impossible to state a generalized "achievable TSS level."

The performance of the TSS removal processes tested did not correlate with a single identifiable attribute of the mill production process or treatment system. A comparison of mills 3 and 5, both west coast kraft mills with aerated lagoons, shows that mill 3 effluent TSS was consistently more susceptible to removal than mill 5. Mill 5 is bleached, whereas mill 3 is unbleached. The aerated lagoon at mill 5 has a much longer retention time than the one at mill 3, and operates at slightly lower average effluent TSS levels.

Mills 1 and 3 are both unbleached kraft with aerated lagoon treatment. In spite of higher initial TSS levels at mill 1 during these tests, the TSS from mill 1 were less susceptible to removal than mill 3. Mill 1 has a slightly longer lagoon retention time (9 days, versus 5.5 days at mill 3) and mill 1 also has an NSSC plant coupled with the kraft process.

No definitive correlations between TSS susceptibility to removal and TSS physical and chemical characteristics were observed. As noted earlier, availability of size distribution by weight rather than volume might yield a meaningful correlation.

Finally, it appears that filtration processes - either sand or mixed media - offer the greatest degree of TSS removal of the processes tested.

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APPENDIX A

LITERATURE REVIEW

This informal technical review provided both theoretical scientific and practical industrial background for this study. Three areas of study were examined. General Studies on Solids Characterization and Removal Processes summarizes broad-spectrum solids characterization studies, and multimedia removal processes. Specific Solids Removal Techniques examines studies of individual types of solids removal techniques: coagulation/sedimentation, filtration, microstraining, and magnetic separation. These studies cover both jar testing and paper mill applications. Finally, the Municipal Treatment Systems examines secondary treatment systems for their potential capability in solids removal. This section includes studies of solids characterization and removal techniques which have been tested in secondary treatment systems in both domestic and military wastewater.

GENERAL STUDIES ON SOLIDS CHARACTERIZATION AND REMOVAL PROCESSES

Solids characterization studies were performed on nine samples of effluent from an activated sludge system at an ammonia-base, bleached sulfite mill.[1] The major conclusions were:

- The effluent suspended solids were almost exclusively biological in nature.
- The particles ranged in size from 1 to 6 microns.
- The majority of the particles observed were dispersed cells (1 to 6 microns), with the next most common being floc particles (5 to 15 microns).
- The samples contained suspended solids concentrations of 90 to 379 mg/l (milligrams per liter), with no significant settleable material.
- 64 to 90 percent of the suspended solids were volatile.
- A preliminary bio-assay test indicated no toxicity to test organisms.

Effluent suspended solids removal studies were conducted at an unbleached Kraft-NSSC (neutral sulfite semi-chemical) cross recovery pulp and paper mill in the southern U.S.[2] The studies included analyses of: coagulation; clarification; and multi-media filtration. Coagulation studies pro-

vided the following conclusions:

- o Suspended solids levels increased with the addition of polymer.
- o Alum was determined to be the best coagulant.
- o Optimum coagulation occurred with 70 to 100 mg/l of alum at pH 4.5.

Sedimentation studies showed that, for a 24 hour settling time, pH adjustment and approximately 70 mg/l alum were required to achieve significant suspended solids removals. Multi-media filtration tests showed suspended solids removals of about 50 percent at a flow rate of 1.35×10^{-3} $m^3/s/m^2$ (2 gpm/ft^2), without chemical addition. The effective media sizes were: coal - 0.95 mm (millimeters); sand - 0.42 mm; and garnet - 0.3 mm.

A Canadian report[3] lists the physical and chemical characteristics of both settleable and non-setteable primary clarifier effluent solids from a Kraft pulp mill. They reported a solids size range of 6 to 80 microns. The authors concluded that Kraft mill effluents may be expected to contain non-proteinous organic nitrogen, making Kjeldahl nitrogen values suspect in terms of the actual food potential of the solids.

Particle size analyses were performed using a Coulter Counter industrial model B, with a 200 micron aperture. The samples were pre-filtered through a 100 micron mesh filter.

Stein and Adams[4] studied the feasibility of suspended-solids removal from an integrated unbleached Kraft-NSSC pulp and paper mill. They concluded that optimum sedimentation of the solids occurred with the addition of 70 to 100 mg/l alum at pH 4.5. They also reported suspended solids removals of about 50 percent at a flow rate of 1.35×10^{-3} $m^3/s/m^2$ (2 gpm/ft^2) without chemical addition.

A Russian paper[5] discussed treatment of biologically purified Kraft mill effluents with aluminum sulfate (alum). The conclusions were that the pH after alum treatment steadily increased to acceptable levels through reaction of hydrogen ions with dissociated hydroxyl groups of lignin.

Gove and Gellman[6,7,8,9] presented a review of the literature pertaining to pulp and paper wastes. Their review included many papers related to solids removal and advanced treatment of pulp mill wastewater.

Five techniques for determining total suspended solids in pulp and paper effluents were investigated by Kendal.[10] The most promising method appeared to be centrifugation, followed by filtration through a 2.4 cm (centimeter) fiberglass filter in a porous-bottomed crucible.

Baskerville and Gale[11] described the use of an instrument for determining the filterability of sludge easily and rapidly. The instrument, called a capillary suction time (CST) meter, measures the specific resistance to filtration of the sample, using the principle of capillary suction of a

filter paper such as chromotography paper. Good, reproducible results were reported.

Lee, et al.[12] reported on the nature of suspended solids in the effluent from bleached and unbleached Kraft and groundwood pulp mills and a fine paper mill. The analyses performed included: total suspended solids (using three different filter types); non-setteable solids; BOD_{30}; total Kjedahl nitrogen; total phosphates; color; and bio-assays. They concluded that non-settleable solids settle and degrade very slowly in receiving waters, and that BOD_{30} and nutrient loading was very low. They also found that the solids were not toxic to fish.

British Columbia Forest Products[29] identified calcium-lignin precipitates as a significant source of non-setteable suspended solids in bleached Kraft mill aerated lagoon effluent. Addition of a brownstock washer at a mill, to reduce soda losses from 2.4×10^{1} kg(55 lb)/ADT down to 5.6 kg(12.4 lb)/ADT (as saltcake), resulted in improved effluent TSS levels.

NCASI[30], in studies conducted at 3 mills and a pilot plant, found that the suspended solids in biologically-treated effluent were biological in nature, and consisted of particles from 1 to several, but generally less than eight microns in diameter. On the order of 25% of the solids were said to be viable biomass. Resistance to coagulation was attributed to adsorption of hydrophilic colloids, rather than charge repulsion.

Bewers and Pearson[31] used serial filtration on Millipore and Whatman filters to determine the size distribution by weight at a modified natural lagoon system serving a bleached Kraft mill in Nova Scotia. They found that about 2/3 of the suspended solids were 0.5-1.0 micron or smaller, and that only 13% of the suspended solids were 5 microns or larger.

NCASI[32] reviewed the nitrogen and phosphorus of biological solids, and reported typical values of 9-10 percent nitrogen and 2-3 percent phosphorus.

Herrmann[33] studied the characteristics of pulp mill treatment system particulates from 3 mills, and found that the solids were nonfibrous material of high carbon and protein content. The particulates were small (<30 micron), and were said to contain appreciable concentrations of calcium and magnesium. Metal-lignin precipitates were postulated to represent a portion of the particulates.

SPECIFIC SOLIDS REMOVAL PROCESSES

COAGULATION/SEDIMENTATION

A method was presented by Surcheck and Tutein[13] for developing a cost-performance factor to determine the best polymer for a given wastewater. The method consists of jar testing using different polymers at different concentrations and then relating optimum dosage to polymer cost.

Sakuma, et al.[14] discussed the clarification of bleached Kraft mill effluents by addition of polyacrylamide (PAA). The variables considered were:

alum dosage; PAA molecular weight and dose rate; and the effect of pH on coagulant efficiency. They concluded that the PAA molecular weight must be greater than 5×10^6 for satisfactory results.

A pilot study to evaluate sedimentation equipment developed by Neptune Microfloc, Inc., and evaluate treatment processes capable of producing reusable water was conducted.[15]

Das and Comas[16] reviewed theoretical adsorption of water-soluble macromolecules onto suspended solids to give either stable dispersions or sensitized flocculation. They also developed a new procedure for use of cationic polyelectrolytes as flocculants for paper fines.

FILTRATION

Canadian researchers[17] studied filtration of a bleached Kraft mill seconday effluent. Secondary treatment consisted of an aerated lagoon system producing an effluent suspended solids (SS) concentration of 50 to 60 ppm (parts per million). The study concluded that SS removals by filtration were in the range of 40 to 50 percent, mainly due to the fine particle size (one micron range) of the dispersed bio-mass solids. The best performance was achieved using a medium grade sand (effective size, 0.56 mm). Granular media filtration by itself was not recommended for solids removal because of the voluminous floc formed after chemical treatment. They also found the optimum alum dosage (at pH 5) to be about 90 ppm, and that 260 ppm alum was required at pH 7.3.

They concluded that lime addition was not an economical coagulation method because of the large quantity required (1,000 ppm).

The NCASI[18] studied the applicability of granular media filtration for removing suspended solids from secondary effluents, from boxboard, bleached Kraft, filled and coated fine paper mills. The study demonstrated on a pilot scale that application of a variety of granular media filtration systems to such diversified effluents could remove only 25 to 50 percent of the residual suspended solids. Backwash materials could not be readily dewatered alone.

Nachbar[19] conducted a pilot plant study of multi-media filtration of activated sludge secondary effluent from a Virginia pulp mill. He concluded that multi-media filtration can remove about 50 percent of the suspended solids and about 30 percent of the BOD at a loading of 3.4×10^{-3} $m^3/s/m^2$ (5 gpm/ft^2). Backwash was reported to be a continual problem.

MICROSTRAINING

A report by a Canadian firm[20] reviewed current filtration and straining methods and research. One of the methods reviewed was microstraining. One installation claimed to obtain 97 percent removal of suspended solids with coagulation, using 35 micron mesh openings, a hydraulic loading of 3.1×10^{-3} $m^3/s/m^2$ (4.6 gpm/ft^2) and a feed concentration (of suspended solids) of about 130 mg/l. Problems tended to occur with adhesive solids blinding the fabric

media and requiring large quantities of backwash water.

MAGNETIC SEPARATION

The concept of high gradient magnetic separation is described by Kolm, et al.[21] They also discussed the work of Samual Frantz, who developed a lab scale separator called the Frantz Ferrofilter. They found that this unit could not economically achieve the magnetic field intensities required to magnetically saturate steel wool or to magnetize weakly magnetic materials, and, thus, has limited application.

Mitchell, et al.[22] described the use of a magnetic device designed to remove weakly magnetic particles from solution. They reported greater than 90 percent removal of coliform bacteria using a device called a high-gradient magnetic separator, with the addition of magnetite to the sample. They also claim 69 percent BOD_5 removal from pulp mill effluent, using the same techniques in their laboratory.

MUNICIPAL TREATMENT SYSTEMS SOLIDS REMOVAL

Identification of the components found in secondary effluents (domestic) was presented by Helfgott, et al.[23] Both chemical analyses (organic) and physical properties were discussed.

Rickert and Hunter,[24] working with municipal wastewater, studied the nature and origin of colloidal meterials present in secondary effluents. They concluded that most of the colloidal particles were formed during secondary treatment rather than being present in the raw wastewater, and were, therefore, biological in nature.

Tchobanogious and Eliassen[25] reported on a studies of filtration of treated domestic wastewater, including information on effluent characteristics. They found the particle size distribution to be bimodal in nature, with the mean size of the smaller particles ranging from 3 to 5 microns and the larger particles ranging from 80 to 90 microns. The weight fraction of the smaller particles was estimated to be 40 to 60 percent of the total. The method used was dark field observation with a stereoscope.

The mean charge on the particles in terms of zeta potential, was about -20 millivolts.

Effluent suspended solids varied between 7 and 14 mg/l. Removal efficiency varied from 15 percent with a 1.0 mm sand size to 40 percent with a 0.5 mm sand size, at a filtration rate of $3.4 \times 10^{-3} m^3/s/m^2$ (5 gpm/ft^2).

Faust and Manger[26] studied the electromobility of colloidal and supracolloidal particles (less than 100 microns) in domestic wastewater. They concluded that the particles were predominantly negatively charged, and that the chemical composition of membrane-filtered particles may be homogeneous.

Sundaram and Santo[27] described the results of laboratory tests on microfiltration using microporous tubes. They reported almost total removal of

suspended solids from military wastes (including laundry, sewage, oil-water emulsions, and turbid water) at filtration pressures of about 3.4×10^4 pascals (5psi).

APPENDIX B

ANALYTICAL METHODS

The methods used for analyses of samples in the work covered by this report and performed by CH2M Hill are listed below. The standard method number given refers to the method in the 14th edition of Standard Methods for the Examination of Water and Wastewater, APHA (1975). Methods modified by CH2M Hill are available on request.

TSS and VSS - Standard Methods 208D and 208E, respectively, modified by CH2M Hill; samples filtered through Reeve Angel 934AH, 4.25 cm filter.

Zeta Potential - Procedure as specified in the Zeta-meter Manual 2nd Edition, as established by Zeta-meter, Inc., New York, N.Y. (1968).

BOD - Standard Method 507.

Particle Size Distribution - Direct count method by visual measurement using a calibrated eyepiece.

APPENDIX C

DATA SUMMARIES

TABLE C-1
RAW DATA — 1976

SAMPLE NO.	PARAMETER	MILL NO.								
		1	2	3	4	5	6	7	8	9
1	BOD (TOT)	29	22	11	114	38	27	32	10	90
	BOD (SOL)	11	4	3	18	12	6	8	3	40
2	BOD (TOT)	22	11	24	124	35	31	118	16	87
	BOD (SOL)	8	5	4	84	9	10	36	4	56
3	BOD (TOT)	230	20	50	413	78	36	41	27	89
	BOD (SOL)	30	12	10	103	23	10	20	12	42
1	COD (TOT)	288	249	214	3,175	660	670	615	230	3,050
	COD (SOL)	188	192	39	1,940	528	519	476	208	2,700
2	COD (TOT)	290	310	224	800	665	425	805	285	3,035
	COD (SOL)	231	292	46	630	520	346	584	240	2,975
3	COD (TOT)	824	237	304	5,665	694	593	945	405	3,325
	COD (SOL)	236	222	70	2,630	545	478	739	306	3,070
1	TSS	48	8	70	928	81	120	52	19	92
	VSS	42	7	63	850	71	91	50	11	92
2	TSS	37	13	77	151	79	72	76	30	50
	VSS	34	11	61	145	61	50	76	18	42
3	TSS	354	12	124	2,510	90	78	91	62	74
	VSS	287	8	108	2,310	74	55	85	36	67
1	TS	777	1,330	1,090	6,000	2,100	1,840	1,200	1,090	5,900
	TVS	210	410	200	3,030	544	326	432	230	4,750
2	TS	920	1,600	880	1,360	2,100	1,970	1,240	1,220	6,300
	TVS	260	380	112	—	1,370	336	478	—	1,730
3	TS	960	1,310	1,030	7,885	2,205	1,960	1,370	1,240	6,340
	TVS	430	304	222	4,020	480	390	540	300	2,430

NOTE: All units in mg/l

TABLE C-1 (continued)
RAW DATA — 1976

SAMPLE NO.	PARAMETER	MILL NO. 1	2	3	4	5	6	7	8	9
1	P (TOT)	.35	.95	.78	7.8	.84	2.4	.54	.82	8.3
	P (SOL)	.05	.59	.06	3.5	.18	1.4	.08	.61	6.2
2	P (TOT)	.24	.93	1.1	—	.84	—	—	—	4.3
	P (SOL)	.05	.62	.04	—	.15	4.9	.06	—	4.0
3	P (TOT)	—	—	1.1	—	—	3.5	—	—	5.2
	P (SOL)	—	—	.05	—	—	3.5	—	—	4.7
1	TKN	5.9	5.8	5.4	31	5.2	8.6	5.0	4.7	6.7
	NO_2/NO_3	.26	.16	.16	.02	.12	.12	.18	.10	.05
	NH_3	.16	3.3	.12	.08	.15	1.2	.28	.83	9.7+
2	TKN	4.2	8.1	8.0	—	—	—	—	—	9.0+
	NO_2/NO_3	.03	.04	.04	.04	.04	.28	0	—	.03
	NH_3	.14	4.7	.23	.05	.30	1.8	.13	—	44
3	TKN	—	—	-	—	—	4.5	—	—	9.0+
	NO_2/NO_3	—	—	.06	—	—	.50	—	—	.25
	NH_3	—	—	.02	—	—	.28	—	—	52
1	PARTICLE SIZE	.54	.60	.57	.92	1.0	.62	.78	.58	.96
2	PARTICLE SIZE	.68	.68	.60	1.0	.95	1.1	.74	.70	.65
3	PARTICLE SIZE	1.1	1.4	.95	.68	.95	1.3	.97	1.3	.80
1	ZETA POT.	-11.4	-6.8	-5.4	-12.0	-10.8	-10.0	-19.9	-12.5	-4.0
2	ZETA POT.	-21.5	-28.2	-15.6	-32.7	-8.5	-15.7	-27.2	-17.4	-5.3
3	ZETA POT.	-44.3	-12.0	-21.2	0	-15.3	-20.5	-37.0	-20.3	-5.3
1	MERCURY	<.025	<.025	<.025	<.025	<.025	<.025	<.025	<.013	2.0
2	MERCURY	0.5	<.013	<.003	—	<.025	<.01	<.01	—	<.002
3	MERCURY	<.025	<.025	<.025	<.025	<.025	<.025	<.025	<.025	<.025

NOTE: All units in mg/l

TABLE C-2

RAW DATA — METALS (Total) — 1976

SAMPLE NO.	PARAMETER	MILL NO.								
		1	2	3	4	5	6	7	8	9
1	CALCIUM	>100	>100	7.8	29.6	131	49.0	22.1	76.0	328
2	CALCIUM	17.1	199	32.0	14.2	113	14.6	>100	85.0	314
3	CALCIUM	25.8	152	41.0	30.0	151	32.0	11.4	72.0	305
1	MAGNESIUM	3.1	3.1	2.7	230	5.3	29.8	1.7	15.3	10.3
2	MAGNESIUM	1.6	3.3	3.2	63.9	5.2	1.3	33.8	15.8	6.3
3	MAGNESIUM	2.1	3.3	3.7	286	5.8	30.5	1.5	15.6	7.2
1	IRON	.84	.84	1.2	1.2	1.3	.99	.83	.62	1.1
2	IRON	.43	.90	1.2	1.1	1.5	.77	.92	.72	1.0
3	IRON	1.2	1.3	.94	2.0	1.5	.70	.98	.71	1.2
1	MANGANESE	.40	.40	.20	<1.0	.57	.33	.48	.63	.81
2	MANGANESE	.19	.51	.43	.71	.68	.57	.26	.67	.76
3	MANGANESE	.40	.48	.53	4.0	.71	.30	.59	.76	>1.0
1	ALUMINUM	.65	.65	1.4	.75	1.8	>2.0	>2.0	.94	1.6
2	ALUMINUM	1.4	.66	1.8	.31	1.9	2.0	>2.0	.99	1.4
3	ALUMINUM	>2.0	.51	1.8	.85	1.8	2.0	>2.0	1.3	1.6
1	ANTIMONY	<.04	<.04	<.04	<.04	<.04	<.04	<.04	<.04	<.04
2	ANTIMONY	<.04	<.04	<.04	<.04	<.04	<.04	<.04	<.04	<.04
3	ANTIMONY	<.04	<.04	<.04	<.04	<.04	<.04	<.04	<.04	<.04
1	ARSENIC	<.04	<.04	<.04	<.04	<.04	<.04	<.04	<.04	<.04
2	ARSENIC	<.04	<.04	<.04	<.04	<.04	<.04	<.04	<.04	<.04
3	ARSENIC	<.04	<.04	<.04	<.04	<.04	<.04	<.04	<.04	<.04
1	BORON	<.005	<.005	<.005	.04	<.005	.29	<.005	.09	.07
2	BORON	.25	.03	.07	.13	.06	.14	.29	.10	.06
3	BORON	.30	.03	.14	.74	.05	.35	.11	.08	.07

NOTE: All units in mg/l

TABLE C-2 (continued)
RAW DATA — METALS (Total) — 1976

SAMPLE NO.	PARAMETER	MILL NO.								
		1	2	3	4	5	6	7	8	9
1	COLUMBIUM	.01	<.02	<.005	—	<.01	—	<.01	<.005	.01
2	COLUMBIUM	<.005	0	<.005	.01	—	.01	<.005	.01	.01
3	COLUMBIUM	.01	<.005	.01	.02	.01	<.005	—	.01	.01
1	CHROMIUM	.05	.07	.11	—	.05	—	<.13	.01	.03
2	CHROMIUM	.02	.02	.03	.05	—	.04	—	.02	.03
3	CHROMIUM	.04	.02	.03	.02	.04	.07	—	.02	.08
1	COBALT	<.04	<.08	<.04	—	<.04	—	.04	<.04	<.04
2	COBALT	<.04	<.04	<.04	<.04	—	<.04	<.04	<.04	<.04
3	COBALT	<.04	<.04	<.04	<.04	<.04	<.04	—	<.04	<.04
1	COPPER	<.20	<.14	<.11	—	<.05	—	.10	.01	.04
2	COPPER	.01	.01	.03	.02	—	.03	—	.01	.03
3	COPPER	.03	.02	.09	.03	.01	.35	—	.03	.09
1	LEAD	<.04	.20	<.14	—	<.08	—	<.19	<.04	.07
2	LEAD	<.04	<.04	<.04	<.04	—	.08	<.04	<.04	<.07
3	LEAD	.08	<.04	.07	<.04	<.04	<.04	—	<.04	<.04
1	MOLYBDENUM	.04	.31	.12	—	.08	—	<.02	<.02	.18
2	MOLYBDENUM	<.02	.09	<.02	<.04	—	<.04	<.04	.09	.16
3	MOLYBDENUM	<.04	.10	.11	.14	.11	<.04	—	.09	<.04
1	NICKEL	<1.0	<1.0	.07	—	<.04	—	<.05	<.04	<.04
2	NICKEL	<.04	.01	<.04	<.04	—	<.04	<.04	<.04	<.04
3	NICKEL	<.04	<.04	<.04	<.04	<.04	<.04	—	<.04	<.04
1	VANADIUM	.07	.03	.10	—	.01	—	.01	.01	.01
2	VANADIUM	.03	.01	.02	0	—	.01	<.005	.01	.01
3	VANADIUM	.04	.01	.02	.03	.01	<.005	—	.03	<.005
1	ZINC	<.20	.30	<.40	—	<.22	—	<.25	.07	.07
2	ZINC	.04	.05	.07	.06	—	.06	3.6	.08	.05
3	ZINC	.08	.09	.10	.36	.05	2.1	—	.13	.14
1	SELENIUM	<.04	.06	.08	—	.08	—	.09	<.04	.06
2	SELENIUM	<.04	.01	<.04	<.04	—	.05	<.04	.05	<.04
3	SELENIUM	.05	<.04	.05	.10	<.04	<.04	—	.05	<.04
1	STRONTIUM	.22	1.1	.36	—	.27	—	.27	.18	.29
2	STRONTIUM	.07	.39	.17	<.04	—	.09	.33	.20	.18
3	STRONTIUM	.10	.35	.20	.22	.28	.31	—	.18	.38
1	ZIRCONIUM	<.01	.01	.01	—	.01	—	.20	<.005	.01
2	ZIRCONIUM	.01	<.005	<.005	<.005	—	<.005	<.005	.01	.01
3	ZIRCONIUM	.01	.01	.01	.01	.01	<.005	—	.01	.02

NOTE: All units in mg/l.

TABLE C-3

RAW DATA — METALS (Soluble) — 1976

SAMPLE NO.	PARAMETER	MILL NO.								
		1	2	3	4	5	6	7	8	9
1	CALCIUM	>100	<100	<10.0	—	>100	—	>20.0	54.6	133
2	CALCIUM	13.4	—	25.2	9.7	—	10.8	27.2	72.7	111
3	CACLIUM	16.9	117	—	22.0	112	27.0	—	57.0	234
1	MAGNESIUM	5.3	11.6	10.6	—	7.3	—	5.7	13.2	8.4
2	MAGNESIUM	1.4	2.8	2.8	49.5	—	1.1	25.7	14.2	5.8
3	MAGNESIUM	2.4	2.9	3.2	252	5.1	26.0	—	13.0	5.8
1	IRON	<1.0	<1.3	4.1	—	<2.2	—	<3.0	.62	.94
2	IRON	.55	.64	1.3	1.0	—	.81	1.4	.74	.84
3	IRON	1.6	1.3	1.1	2.0	1.6	1.1	—	.76	1.3
1	MANGANESE	.55	1.6	.83	—	.81	—	1.6	.58	.70
2	MANGANESE	.17	.35	.42	.57	—	.51	.15	.35	.75
3	MANGANESE	.36	.20	.46	4.1	.67	.27	—	.66	.91
1	ALUMINUM	5.3	2.3	7.6	—	3.5	—	8.5	1.8	1.4
2	ALUMINUM	1.6	.73	2.2	.41	—	2.7	4.5	2.5	1.0
3	ALUMINUM	5.3	.65	2.8	4.8	2.8	4.5	—	4.8	2.0
1	ANTIMONY	<.04	<.04	<.08	—	<.04	—	<.08	<.04	.06
2	ANTIMONY	<.04	<.04	<.04	<.04	—	.05	<.04	<.04	.05
3	ANTIMONY	<.04	<.04	.06	<.04	<.04	<.04	—	.05	<.04
1	ARSENIC	<.04	<.04	.05	—	<.04	—	<.05	<.04	<.04
2	ARSENIC	<.04	<.04	<.04	<.04	—	<.04	<.04	<.04	<.04
3	ARSENIC	<.04	<.04	<.04	<.08	<.04	<.04	—	<.04	<.04
1	BORON	.14	<.005	<.005	—	<.005	—	.09	.04	.07
2	BORON	.23	.03	.06	.19	—	.10	.15	.10	.12
3	BORON	.20	.19	.10	.63	.15	.20	—	.08	.18

NOTE: All units in mg/l.

TABLE C-3 (continued)

RAW DATA — METALS (Soluble) — 1976

SAMPLE NO.	PARAMETER	MILL NO.								
		1	2	3	4	5	6	7	8	9
1	COLUMBIUM	<.005	<.005	<.005	.01	<.005	.01	<.005	.01	.02
2	COLUMBIUM	<.005	.02	<.005	.02	.01	.01	.02	.01	.02
3	COLUMBIUM	<.005	<.005	.01	.03	.02	.02	.02	.01	.02
1	CHROMIUM	.02	.02	.02	.06	.02	.01	.03	.02	.03
2	CHROMIUM	.02	.02	.03	.06	.03	.05	.03	.02	.03
3	CHROMIUM	.05	.03	.02	.08	.03	.03	.02	.03	.03
1,2,3	COBALT	<.04	<.04	<.04	<.04	<.04	<.04	<.04	<.04	<.04
1	COPPER	.01	.01	.02	.02	.01	.02	.03	.02	04
2	COPPER	.01	.02	.02	.02	.02	.03	.06	.02	.03
3	COPPER	.04	.02	.11	.11	.02	.07	.03	.03	.04
1	LEAD	<.04	<.04	<.04	<.04	<.04	<.04	.06	<.04	<.04
2	LEAD	<.04	<.04	<.04	<.04	<.04	<.04	<.04	<.04	<.04
3	LEAD	.06	<.04	<.04	.09	<.04	<.04	<.04	<.04	<.04
1	MOLYBDENUM	.06	.07	.06	<.02	<.02	<.02	.02	.03	.17
2	MOLYBDENUM	<.02	.10	<.02	.03	.40	.10	.03	.03	.14
3	MOLYBDENUM	.12	.12	.07	.10	.12	.10	.10	.12	.17
1	NICKEL	<.04	<.04	<.04	<.04	<.04	<.04	<.04	<.04	.06
2	NICKEL	<.04	.08	.05	<.04	.04	<.04	.04	<.04	.06
3	NICKEL	.04	.06	<.04	.11	.06	<.04	.06	<.04	.06
1	VANADIUM	.01	.01	.03	.02	<.005	.01	<.005	.01	.01
2	VANADIUM	.04	.02	.02	.01	.01	.01	.02	.01	.02
3	VANADIUM	.05	.02	.02	.04	.01	.02	.01	.02	.02
1	ZINC	.06	.06	.06	.26	.05	1.2	.05	.08	.08
2	ZINC	.04	.13	.11	.09	.14	.12	>2.0	.08	.06
3	ZINC	.08	.11	.09	.46	.07	1.9	.09	.15	.12
1	SELENIUM	<.04	<.04	<.04	<.04	<.04	<.04	<.04	<.04	.04
2	SELENIUM	<.04	<.04	<.04	<.04	<.04	<.04	<.04	<.04	.04
3	SELENIUM	<.04	<.04	<.04	.05	<.04	<.04	<.04	<.04	<.04
1	STRONTIUM	.28	.28	.10	.27	.20	.40	.09	.20	.40
2	STRONTIUM	.08	.40	.19	.09	.30	.10	.39	.22	.33
3	STRONTIUM	.12	.38	.22	.28	.35	.38	.11	.21	.50
1	ZIRCONIUM	.01	.01	.01	<.005	<.005	<.005	<.005	<.005	.01
2	ZIRCONIUM	<.005	.01	<.005	.01	.01	.01	.01	<.005	.01
3	ZIRCONIUM	.01	.01	<.005	.01	.01	.01	.01	.01	.01

NOTE: All units in mg/l.

TABLE C-4
SUPPLEMENTAL DATA — 1977

PARAMETER	MILL NO.					
	1	2	3	4	5	6
TSS	67	8	89	843	45	60
VSS	58	8	65	792	37	40
TS	1,090	1,600	820	5,490	2,260	3,180
TVS	430	710	280	2,750	710	740
TKN (TOT)	4.9	5.0	9.6	—	6.1	4.7
TKN (SOL)	2.4	4.1	2.0	3.4	1.7	1.9
ORGANIC N (TOT)	4.7	3.1	8.6	—	5.8	4.5
ORGANIC N (SOL)	2.2	2.2	1.0	3.2	1.4	1.7
NH -N	0.23	1.9	1.0	0.20	0.31	0.21

NOTE: All units in mg/l.

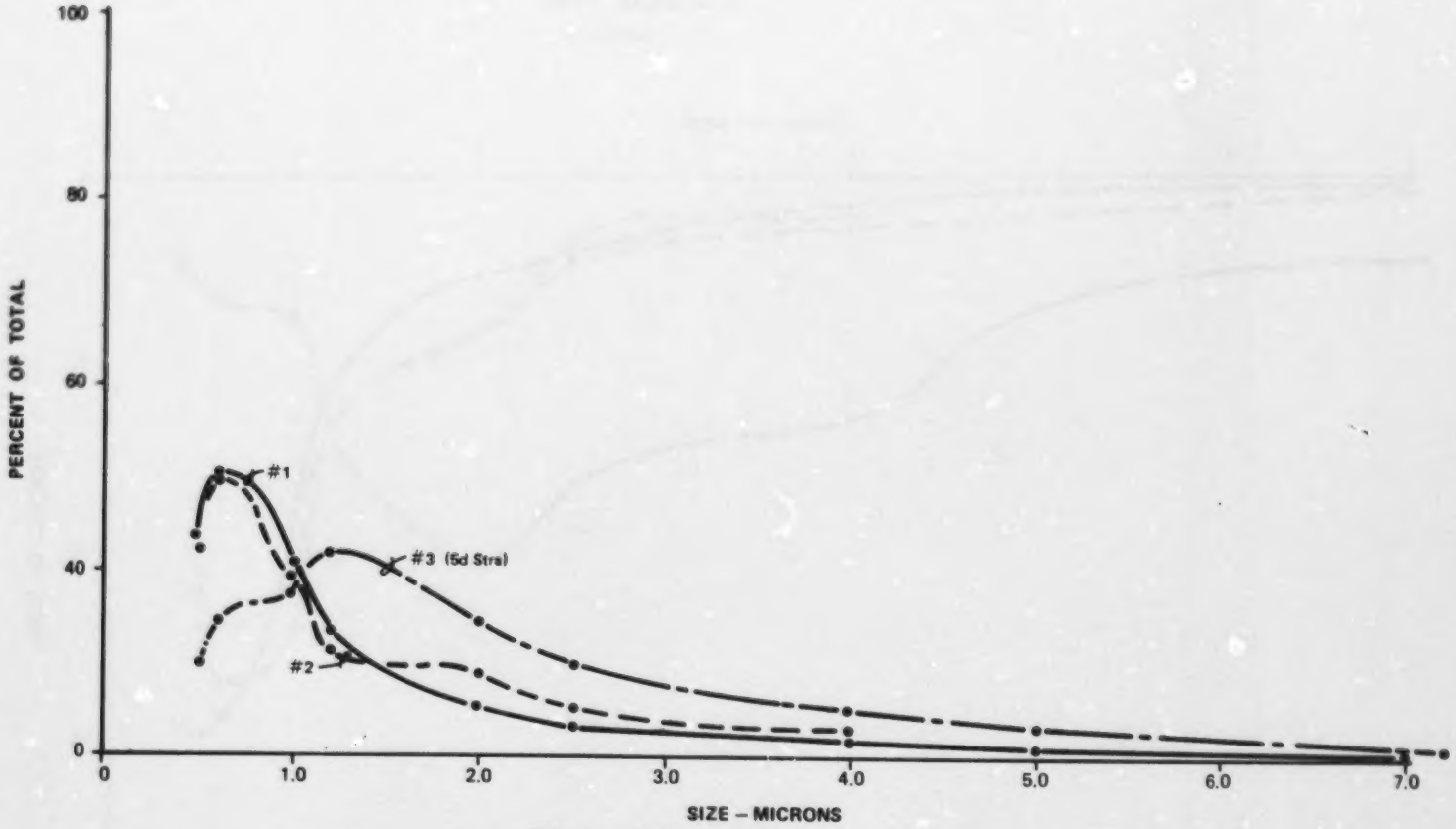

Figure C-1

MILL NUMBER 1

PARTICLE SIZE (DIRECT COUNT METHOD)

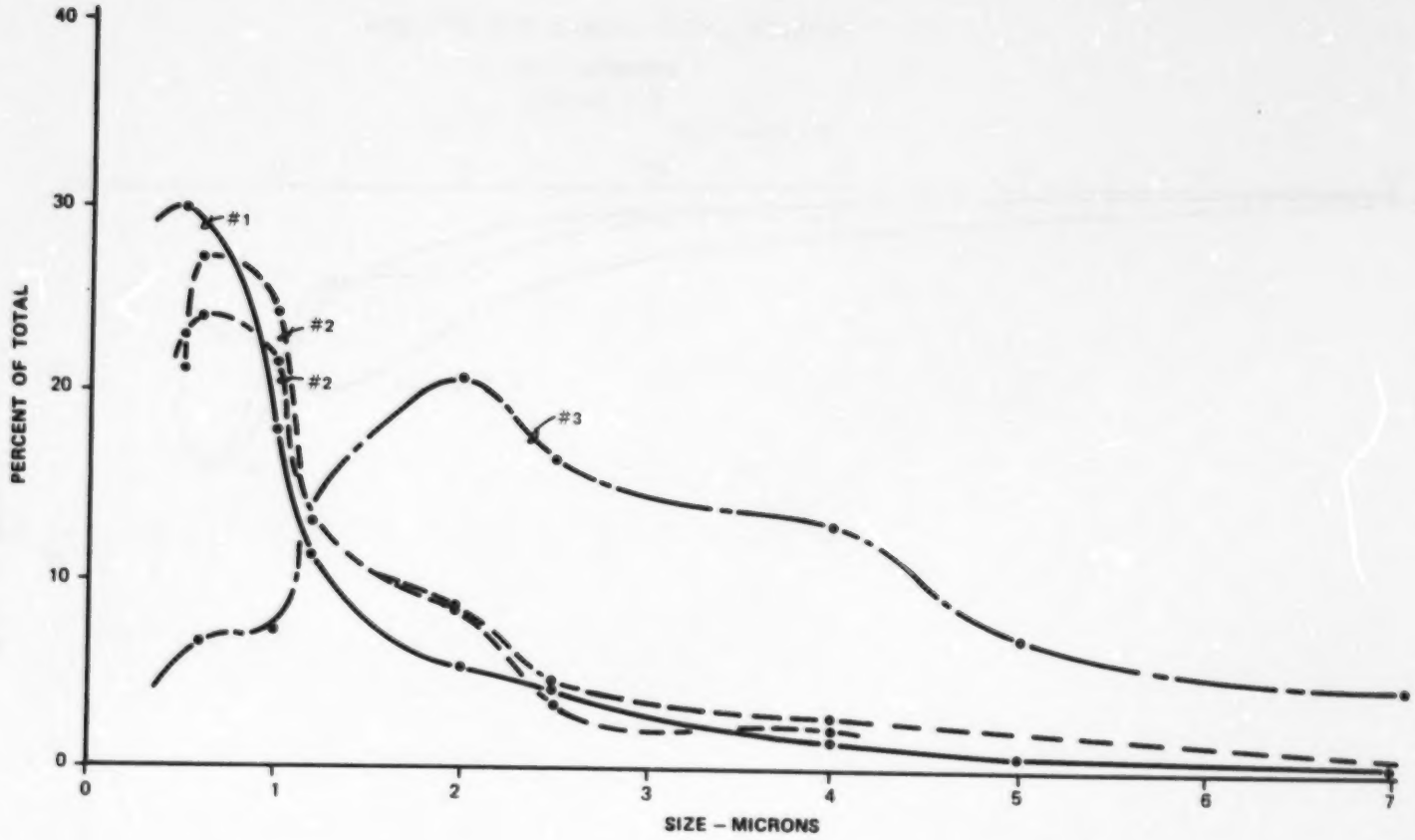

Figure C-2
MILL NUMBER 2
PARTICLE SIZE

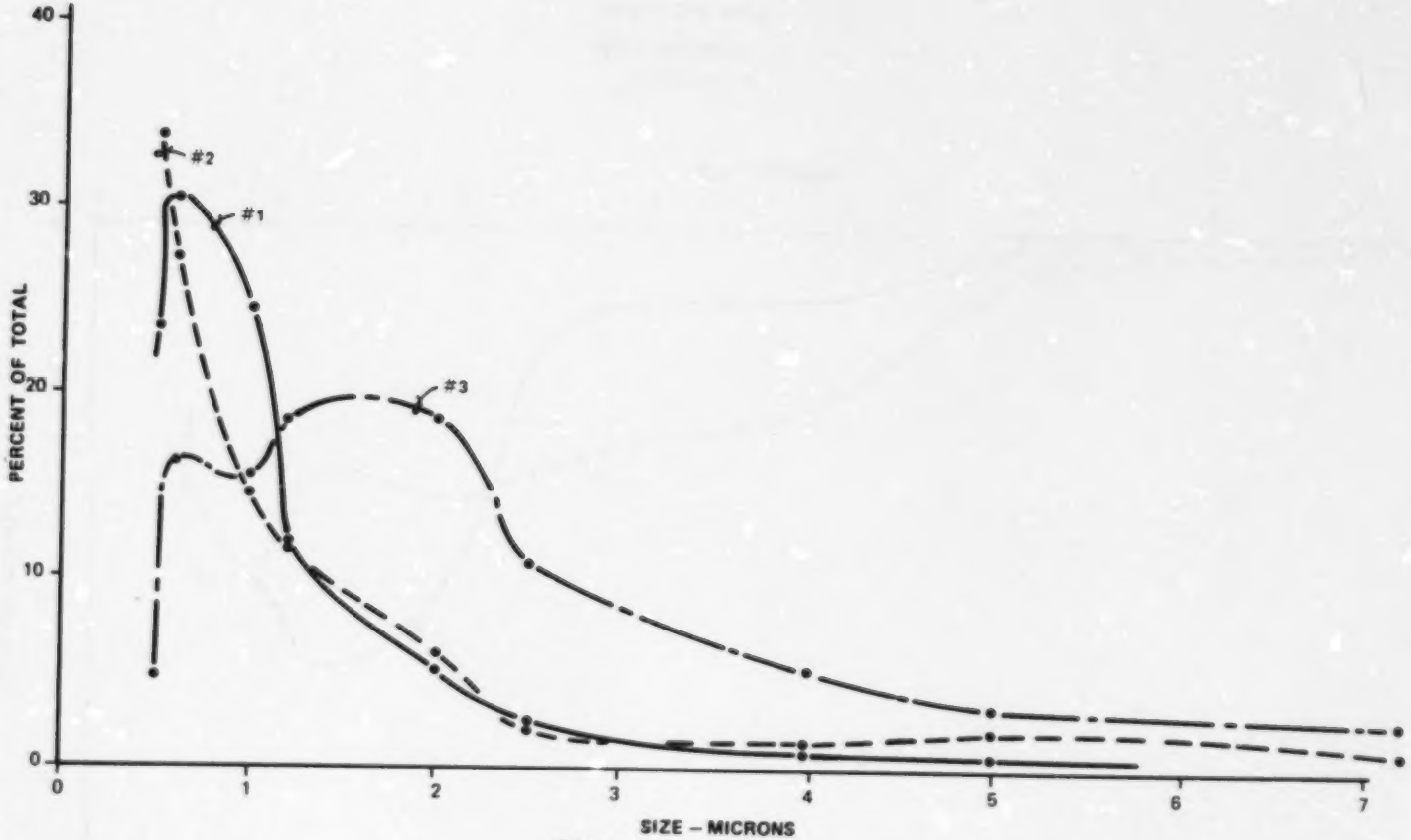

Figure C-3
MILL NUMBER 3
PARTICLE SIZE

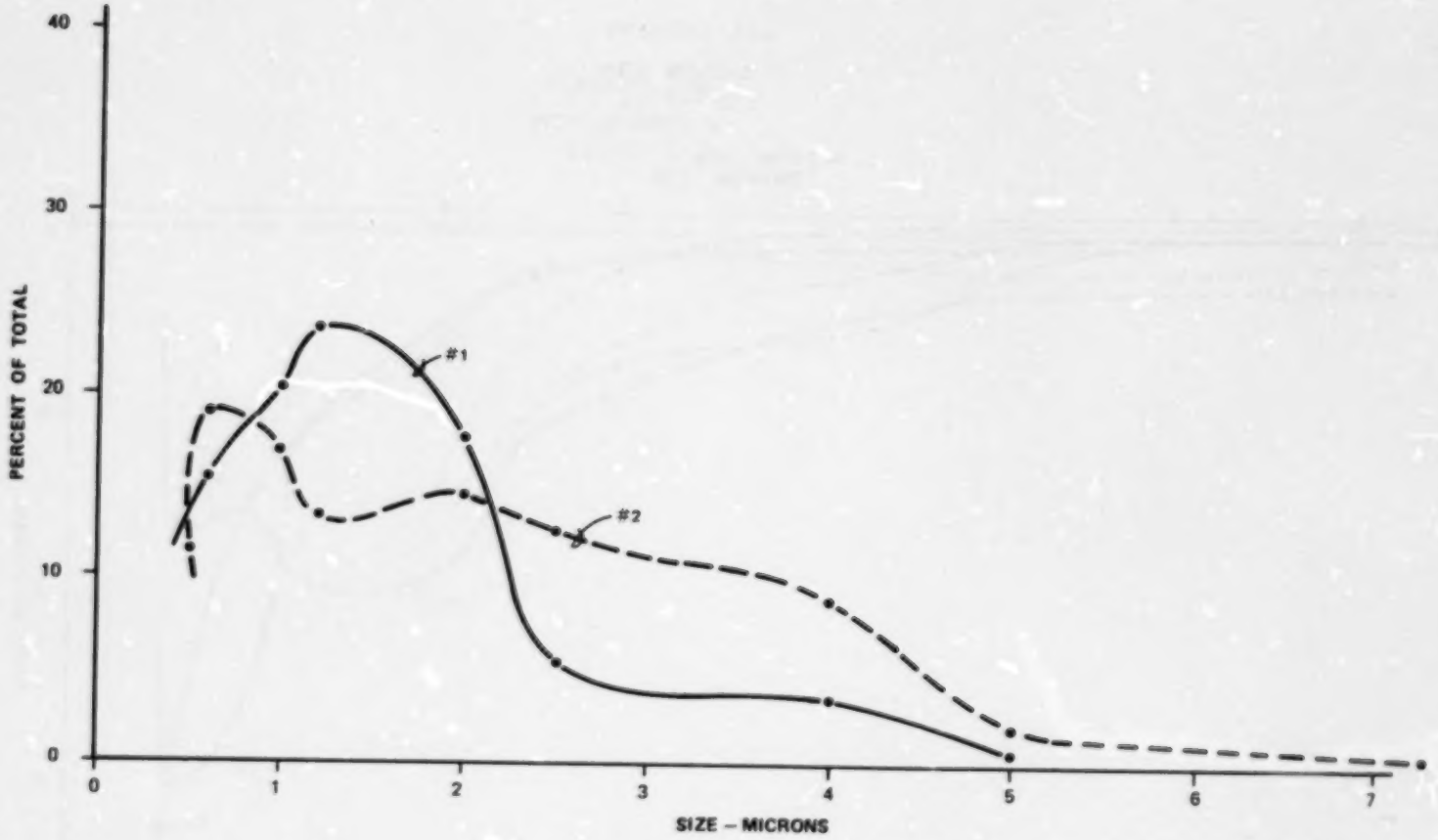

Figure C-4
MILL NUMBER 4
PARTICLE SIZE

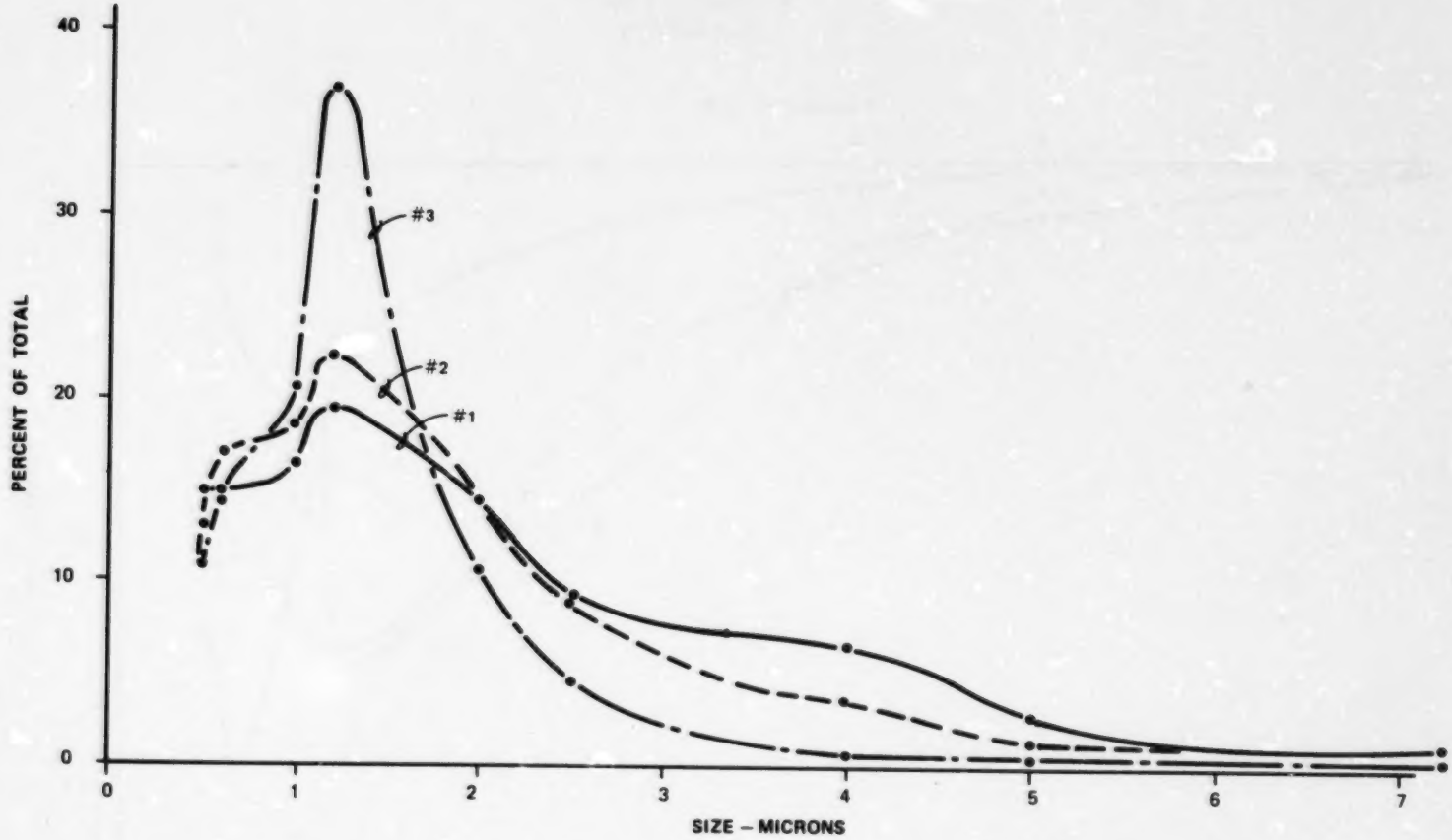

Figure C-5
MILL NUMBER 5
PARTICLE SIZE

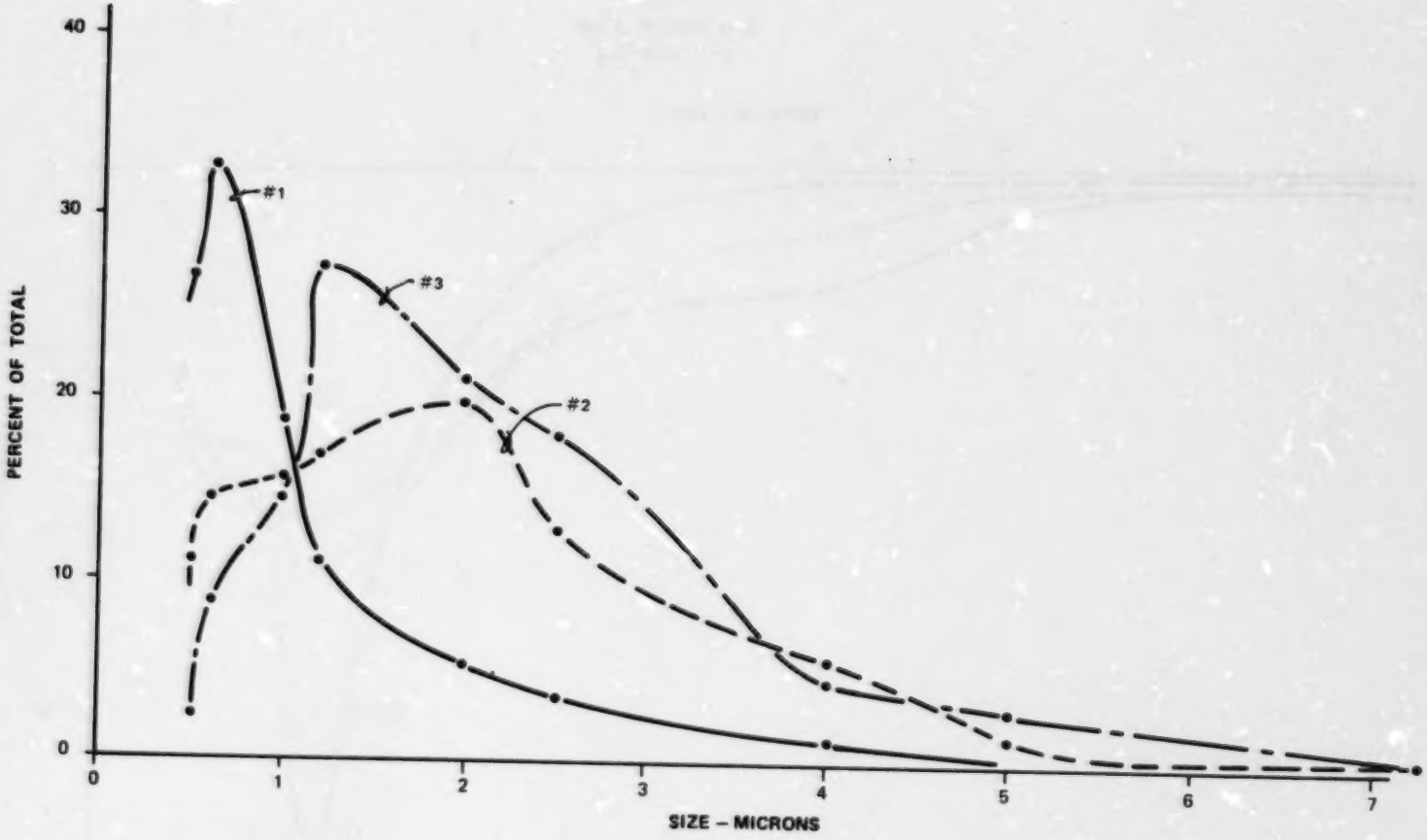

Figure C-6
MILL NUMBER 6
PARTICLE SIZE

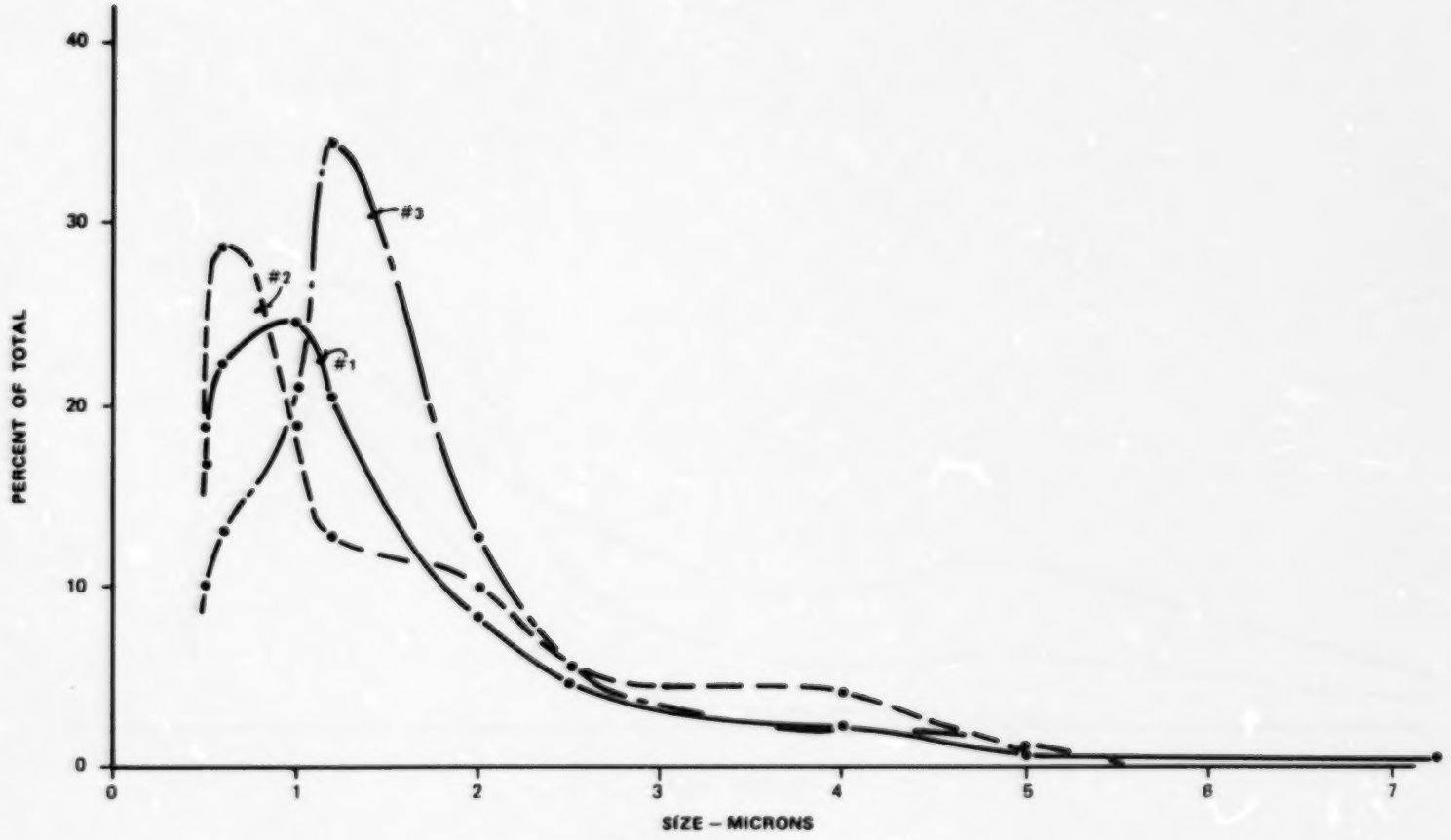

Figure C-7
MILL NUMBER 7
PARTICLE SIZE

PARTICLE SIZE
MILL NUMBER 8
FIGURE C-8

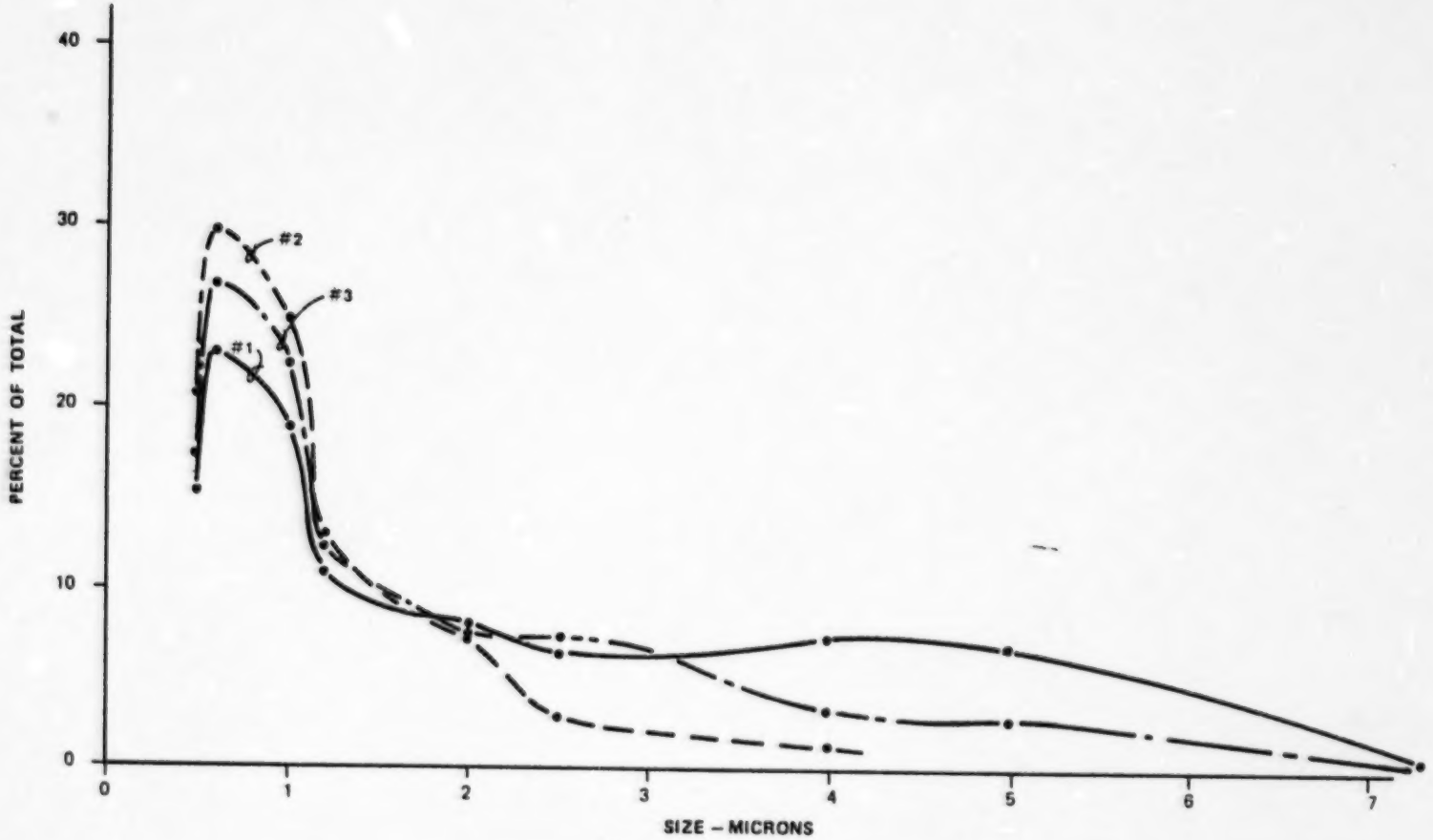

Figure C-9

MILL NUMBER 9

PARTICLE SIZE